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Wellman Steelworks Plant

Over a long period we have served the Steel Industry and Metallurgical trades as Specialists in the design and construction of machinery and plant involving engineering development to suit particular working conditions. Much of the machinery and plant used at the present time in the production of steel was originally designed and introduced by 'Wellman'.

Photo above shows three 60-ton Wellman Casting Cranes operating in a modern Steelworks.

THE WELLMAN SMITH OWEN ENGINEERING CORPORATION LIMITED
VICTORIA STATION HOUSE, LONDON, S.W.1 WORKS: DARLASTON, SOUTH STAFFS

SIR JOHN CRAIG, C.B.E., D.L.

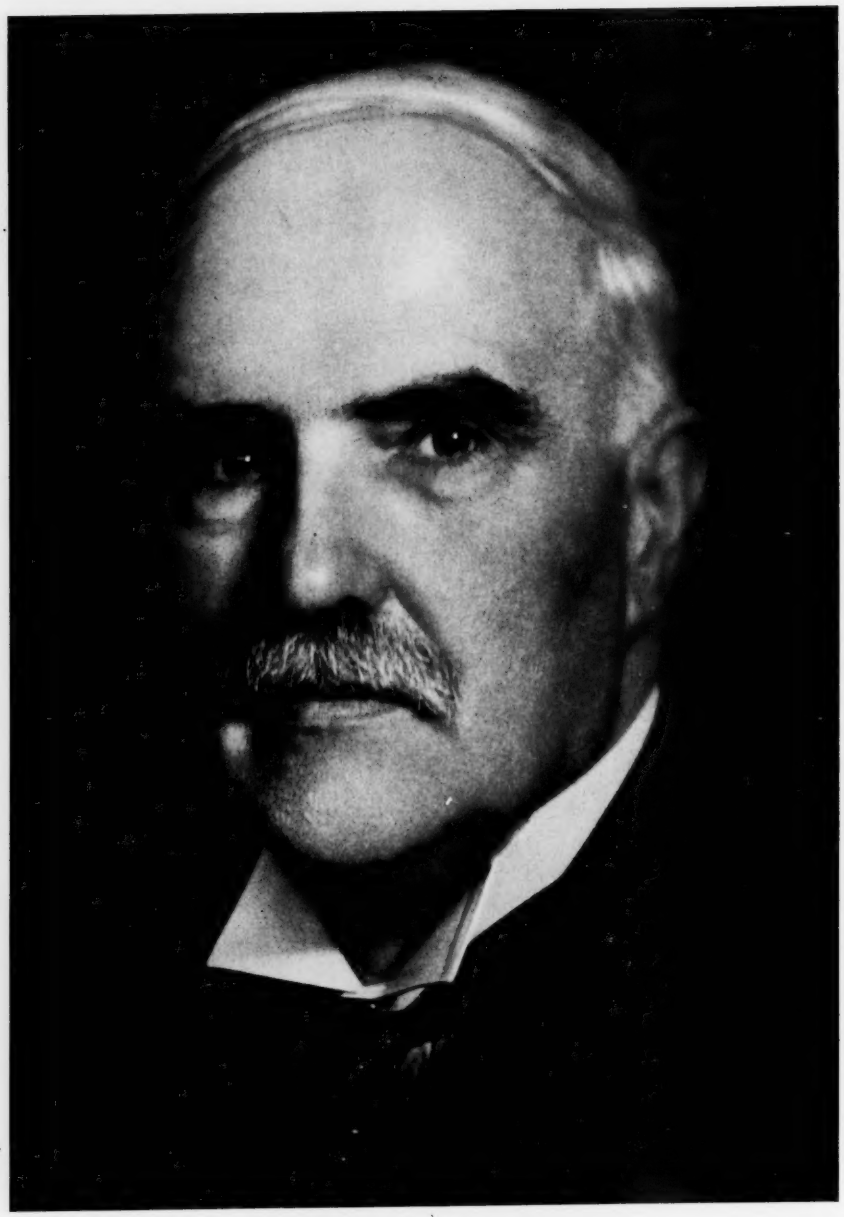
SIR JOHN CRAIG, Chairman and Joint Managing Director of Colvilles, Ltd., has occupied for many years an eminent position in the British steel industry. Born in Clydesdale, Mossend, in 1874, he was educated at Motherwell and then, at the age of fourteen, he joined the firm of David Colville & Sons, Ltd., where he received his early training. In 1895, he was chosen to represent the company on Glasgow Royal Exchange, and he combined these duties with those of general outside representative for many years, during which time he became well known throughout the iron and steel trade.

In February 1910, Sir John was made a Director of Colville & Sons, Ltd., and in December 1916, he was elected Chairman of the Board. Under his Chairmanship, Colvilles began to extend their interests, in order to cover adequate supplies of raw materials and products essential to the successful operation of their steelworks : examples of this type of expansion are to be found in the ownership of coal mines, the manufacture of ingot moulds and, later, the building of rolling mills. In addition to promoting the interests of his own firm, Sir John always took an active and prominent part in the steel trade generally, and his thorough and expert knowledge proved invaluable during the First World War, when his services and advice were in constant demand. His work was officially recognised when, in June 1918, he was created a Commander of the Order of the British Empire.

Sir John's business interests have extended over a wide field : early in his career he took an interest in the firm of Messrs. Harland and Wolff, Ltd., Belfast, and he has been a Director of the Company since 1924. He is also Chairman and Joint Managing Director of the Colville Group ; Chairman of the Scottish Temperance and General Assurance Co., Ltd., a Director of the Bank of Scotland, and a Director of the British Iron and Steel Corporation, Ltd. He was elected President of the Iron and Steel Institute for the years 1940 to 1942, and is also past-president of the National Federation of Iron and Steel Manufacturers.

Sir John's many years of public service, and the assistance he rendered during the last war, were recognised when, in 1943, the honour of Knighthood was conferred upon him by the King.

Apart from his wide business interests, he has given over 40 years' service to the Y.M.C.A., and has for a long period taken an active part in the Motherwell branch, where, in 1900, Sir John was appointed President. He is a Deputy Lieutenant and a Justice of the Peace in the County of Lanarkshire. He has a great interest in Industrial Welfare, and recently gifted " The Craig War Memorial Home " at Skelmorlie on the Firth of Clyde for convalescent employees of Colvilles, Ltd.



Sir John Craig, C.B.E., D.L.
President 1940 to 1942.

Thoughts on the Special Summer Meeting in Switzerland, 1947

By Professor Dr. R. Durrer (Hon. Vice-President of the Institute, Chairman of the Reception Committee in Switzerland)

IT is not often that the Iron and Steel Institute holds an Overseas Meeting. It is therefore a great pleasure, and indeed an honour for Switzerland, with its small iron and steel Industry, that such a large number of representatives of the British iron and steel industry and their Ladies should come here to exchange scientific and technical ideas and to visit our factories and industrial installations. We Swiss extend a very warm welcome to our British guests ; those of us who are engaged in the iron and steel trade are ever mindful of, and thankful for, the all-important pioneer work done by Britain in the development of the processes for the production of iron and steel.

I hope that your short visit may not only have been worth while from the technical point of view but that you have also been able to recuperate in our mountain country, from the strain and struggle of recent years. For my own part, I would like to express my sincerest good wishes, both as a Member of the Institute, and as a friend, to my technical colleagues in Britain and to their wives.

Iron is one of the essentials in our present-day life. It is needed for the furtherance of our livelihood in time of peace ; it is a vital element in the maintenance of our very existence. The exchange of ideas about the production and treatment of this metal is therefore of outstanding importance, and we Swiss steelmakers are specially thankful to have had the opportunity of learning from our colleagues in the great British iron and steel industry.

But far more important even than this exchange of technical ideas is the opportunity afforded for men and women of many nations from all corners of the earth to meet one another individually as friends. It must be clear to anybody who faces the facts, that an overwhelming catastrophe for the whole of the human race can only be avoided by better understanding on all sides—by all working together, not against one another. Modern technical achievements daily make the world smaller. Countries and continents are forced ever closer and closer together. This process can go on without mortal danger to us all only if the peoples of the world can learn to know and respect one another and can develop a feeling of universal human brotherhood which will transcend political frontiers and barriers.

The state of the world today offers small hopes for the future ; yet beneath the apparently all-embracing cult of materialism which has swept over the earth, there still slumber in many of us great moral and spiritual forces ; these must be brought to bear. The alternative is inescapable ; either we keep to our present way, daily drawing nearer to the abyss, or we must turn and face the moral issues with all those qualities that make up the true man in us.

With these ideas in mind, I am more than ever thankful that it has been possible for all of us friends to meet and talk together in the peaceful land of our ancient Swiss Confederation. May the benefits of the Meeting be far-reaching.

SPECIAL SUMMER MEETING IN SWITZERLAND, 1947

A Special Summer Meeting of the Iron and Steel Institute was held in Zürich, Switzerland, on Thursday and Friday, 10th and 11th July, 1947. At the kind invitation of Dr. A. Rohn, President of Schweizerischen Schulrates, the sessions took place in the Auditorium Maximum of the Eidgenössische Technische Hochschule ; they commenced at 9.30 a.m. on both days, and finished at about 12.30 p.m. Dr. C. H. Desch, F.R.S., President of the Institute, was in the Chair.

Opening of the Proceedings

At the commencement of the Thursday session, at which the Members' Ladies were also present, Dr. **A. Rohn,** President of the Swiss Technical School Council, speaking in French, offered a cordial welcome to the Institute. He said that in meeting in the Polytechnic the Institute was meeting, as it were, on the soil of the Swiss Confederation itself, since the Polytechnic was the only educational establishment for which the Swiss Government was responsible, and was evidence of the interest taken by the Confederation in applied science. In Switzerland, primary, secondary, and university education were the responsibility of the cantons, which adapted the instruction given to the varied cultural and other requirements of the different parts of the country.

The visit of the Institute was all the more welcome by reason of the fact that it was due to the sympathy felt for, and the appreciation of, Switzerland and her institutions as well as to professional interest. Switzerland lacked natural resources and suffered from many other disadvantages, so that the development of her industries might seem to be something of an enigma. The fact was, however, that these unfavourable economic conditions had obliged the country to make the best possible use of its intellectual resources and manual skill. " The beauty of our country and the eternal snow of our mountains (the source of our water-power), are almost our only natural resources," he said, " and our people, if they are to maintain a high standard of living, must do so by hard work. We are obliged to export a large part of our production, and we consume in Switzerland only 60% of our total production and only 15% of our production of machinery." These figures were relatively lower than those of any other industrial country.

Switzerland had to buy her raw materials abroad and, the level of wages being high, Swiss exports were possible only because of the high quality of her products. It was the absence of raw materials which had made it necessary to produce goods of the highest quality. All her educational establishments had had to adapt themselves to this necessity and had to train both manual and intellectual workers to produce work of a very high standard.

In the domain of applied science this was the task of the Polytechnic, which was called upon to train young engineers who had already received a sound fundamental scientific training to apply it in a way showing initiative, and sometimes in a creative spirit. During the past year the Swiss Government had granted the sum of 27 million francs to enlarge the laboratories and research institutions of the school, because scientific research was a necessary complement to higher technical education.

Switzerland was a small country, surrounded by mountains and containing peoples of different races, languages, and religions, but united for centuries by geographical conditions and by their love of independence. It was the first country to bring about, albeit on a small scale, a free union of peoples of very different mentalities, respecting their rights and duties under a constitution based on respect for the freedom and dignity of the human being. There were in Switzerland four national languages, of which one, Romansch, was spoken by only 44,000 people, but this language had been recognized during the last war to indicate the equality, on a moral basis, of all the people of the country.

The visits to different parts of the country to be made by the Institute would give those taking part in them some idea of the varied nature of Switzerland. They would meet everywhere a reception of democratic simplicity. Life in a country much of which was unproductive, and the constant view of their high mountain peaks, had imposed on the Swiss people this simplicity, and had stabilized their political conceptions. The Members of the Institute, however, could be certain that all the industrial enterprises and

other places which they would visit would be very happy indeed to receive them, because Switzerland had always attached the greatest importance to her relations with Great Britain. Cultural, industrial, and economic relations began with relations of friendship between peoples.

" We are certain," Dr. Rohn said in conclusion, " that your visit to Switzerland will contribute to the development and strengthening of the friendly relations which already exist between us, and create new bonds between you and your Swiss colleagues. I sincerely hope that these relations of friendship and sympathy will develop. On behalf of all your Swiss friends I wish to express our goodwill towards your eminent President and for the growth of your Institute and the influence which it exerts in an essential domain of human activity, that of iron and steel, which rules the world in time of peace and in time of war.

" Permit me also, to pay homage to your country for the magnificent example of civic courage which it gave during the war, and for the dignity and spirit of discipline with which your people have adapted themselves to the innumerable social, economic, and political difficulties which have resulted from the war. We all know, whether we belong to small countries like my own or to great countries such as yours, that we shall have to pass through difficult times before the troubles resulting from the time of torment through which Europe has passed have subsided, but we are certain that our British friends will surmount all the difficulties which confront them, thanks to the indomitable energy of which you have given such striking proofs during the war. We know that you will maintain your traditions, your conceptions of liberty and respect for human personality, and your concern for the welfare of mankind." (*Applause.*)

The **President** (Dr. C. H. Desch, F.R.S.), after giving an English summary of Dr. Rohn's address, thanked Dr. Rohn for his speech of welcome and for his share in the magnificent reception which the Institute was being given in Zürich. He agreed most heartily with what Dr. Rohn had said as to the relations between their two countries. Those relations had been of the friendliest and closest kind for very many years; the two countries held a common democratic tradition in which they had to some extent led the world. Many would recall Wordsworth's famous lines:

> " Two voices are there,
> One of the sea, one of the mountains;
> Each a mighty voice.
> In each from age to age thou didst rejoice,
> They were thy chosen music, Liberty."

Wordsworth went on to refer to the democratic traditions of the two countries of which he was speaking, Switzerland and England.

That poem of Wordsworth's expressed what had been the feelings of England for Switzerland over a long period of years; and it was a particular pleasure that, now that the war was over, it was possible once again to pay a visit to Switzerland, with its magnificent tradition of liberty and at the same time with its very high technical standards. (*Applause.*)

At the conclusion of this official welcome the Ladies withdrew, and the Meeting turned its attention to the discussion of technical papers.

Presentation of Papers

The following papers were presented for verbal discussion at the meeting:

Thursday, 10th July

For Joint Discussion:

" Electric Smelting," by Professor Dr. R. Durrer.

" The Production of Iron and Steel with Oxygen-Enriched Blast," by Professor Dr. R. Durrer.

" Possibilities for the Extended Use of Oxygen in the British Iron and Steel Industry," by M. W. Thring.

For Joint Discussion:

" Hydrogen and Transformation Characteristics in Steel," by Professor J. H. Andrew, Dr. H. Lee, H. K. Lloyd, and N. Stephenson.

" Hydrogen in Steel Manufacture," by Dr. C. Sykes, F.R.S., H. H. Burton, and C. C. Gegg.

Friday, 11th July:

" Observations on Conducting and Evaluating Creep Tests," by W. Siegfried.

For Joint Discussion:

" Steels for Use at Elevated Temperatures," by Dr. C. Sykes, F.R.S. (Second Hatfield Memorial Lecture).

" Requirements of Steel for Gas Turbines," by H. R. Zschokke and K. H. Niehus.

" The Scaling Behaviour of High-Strength Heat-Resisting Steels in Air and Combustion Gases," by W. Stauffer and H. Kleiber.

At the conclusion of the discussion on these papers (which is included in this issue of the *Journal*, pp. 369–390), Mr. D. A. Oliver presented Special Report No. 38, " A Symposium on Powder Metallurgy," giving a short résumé of its contents and of its discussion* in London on 18th and 19th June, 1947.

* To be published in the December issue of the *Journal*

The following papers were prepared specially for the Meeting, but were not formally presented or discussed :

" Review of the Swiss Metal and Engineering Industries," by W. M. von Orelli.
" A New Method of Welding Rail Joints," by F. Wörtmann.
" Electric Smelting Plant at Choindez," prepared from a paper by E. Gehrig.

Of the above-mentioned papers, the Second Hatfield Memorial Lecture by Dr. Sykes was printed in the July issue of the *Journal*, and all the others in the June issue.

Close of the Proceedings

At the end of the Friday session, the **President** (Dr. C. H. Desch, F.R.S.) said that, although the stay of the Members in Switzerland would continue for some time, the present Meeting was the last which was being held, and he would ask Dr. A. Rohn to say a few words.

Dr. **A. Rohn**, speaking in French, said that the excellent programme which had been drawn up for the Summer Meeting of the Institute called for a few words of adieu from him, at the end of the formal sessions in the Federal Polytechnic. He would obviously have preferred to say goodbye in a week's time, at the end of the Institute's visit, because the Members would then have had the benefit not only of the technical discussions and works visits but of seeing some of the natural beauties of Switzerland, he hoped in brilliant sunshine and with an agreeable temperature. He hoped, in particular, that they would enjoy good weather for their visit to the Jungfraujoch, where the railway station and post office were the highest in Europe, at an elevation of over 11,000 ft.

Their programme of excursions would take them from Zürich to Central and Western Switzerland. They would find that the form of Swiss German spoken in the cantons changed a little every few kilometres, and that the French language replaced the German within 100 km. of Zürich. They would not be visiting the Ticino or the Grisons, where the other two languages of Switzerland were spoken, but he hoped that their next visit to Switzerland would permit them to do so.

He would like to thank the Members of the Institute once again and very warmly for visiting Switzerland, and in particular for holding their technical discussions in the hall of the Polytechnic. He hoped that their deliberations had been fruitful, that their visits to industrial enterprises and their excursions would give them every satisfaction, and that the impressions which they had received and the friendships which they had made would encourage them to come back soon and to acquire a better understanding of the country and of the mentality of its people, which was so like that of the English, and so create new bonds between them. It was in that spirit that he said " Au revoir " and not " Adieu."

The **President** thanked Dr. Rohn for his very kind remarks, and, since the Jungfraujoch had been mentioned, he recalled that there was there a laboratory of a quite remarkable kind. Many Members of the Institute, he said, were concerned with the flow of crystals under pressure—metallic crystals—but there was a laboratory at the Jungfraujoch, at a height of 11,000 ft., in which the flow of crystals under pressure was studied under very different conditions. The laboratory was hollowed out inside a glacier, so that the temperature was always a degree or two below freezing point. It was magnificently equipped, and there ice was studied as if it were a metal, sections being cut, examined under the microscope, photographed, and so on. A good many English research workers had spent some time there, and the results were of the most striking kind. Although ice was a very different material from steel, there was a considerable resemblance between the information obtained in the one case and that obtained in the other, and the proceedings of the laboratory were of the very highest scientific interest.

The first time he went to Grindelwald after the Jungfraujoch railway had been built, some daring climbers were attempting to scale what had been regarded as the unclimbable face of the Eiger. That night a light was seen high up in the mountain, and some people thought it must mean that the climbers had reached there ; but they were told " No, that is the railway station "—there was a railway station just behind that unclimbable face. The engineering accomplishments of Switzerland were astonishing, and the Jungfraujoch railway was one of the most remarkable.

In conclusion, he wished to thank, on behalf of the Institute, all those who had done so much to make the Meeting a success. Dr. Durrer and the Members of the Reception Committee had organized the Meeting magnificently, and Dr. Rohn and all those connected with the Polytechnic had earned the gratitude of the Institute for allowing the sessions to be held in the splendid buildings of the Polytechnic. Cordial thanks were also due to Nationalrat Ernest Speiser, the President, and Mr. Walter von Orelli, the Secretary, of the Swiss Association of Machinery Manufacturers, and to a number of other gentlemen whom he named.

The President's remarks were endorsed by the Meeting with acclamation, and the proceedings then terminated.

Visits and Excursions

In conjunction with the technical sessions for the discussion of papers, an interesting programme of visits to works, laboratories, places of interest, and beauty spots was arranged for the Members and their Ladies. The following Reception Committee, of which Professor Dr. R. Durrer kindly consented to be the Chairman, undertook to co-ordinate the arrangements in Switzerland:

Professor Dr. R. Durrer, Managing Director, Gesellschaft der Ludwig von Roll'schen Eisenwerke, A.G., Gerlafingen,
Regierungsrat J. Henggeler, President, Zürich Kantonal Government,
Dr. A. Ith, Director, Verkehrsverein, Zürich,
Dr. A. Lüchinger, Lord Mayor of Zürich,
Dr. A. Masnata, Director, Schweizerische Zentrale für Handelsförderung, Lausanne,
Herr F. Niederer, Director, Schweizerische Zentrale für Verkehrsförderung, Zürich,
Professor Dr. A. Rohn, President of the Schweizerischen Schulrates,
Nationalrat E. Speiser, Director, Brown Boveri et Cie, President, Verein Schweizerischer Maschinen-Industrieller,
A. N. Williamson-Napier, Esq., British Consul-General, Zürich.

The following Ladies took care of the feminine side of the arrangements:

Frau M. Durrer, Gerlafingen,
Frau E. Henggeler, Zürich,
Frau B. Lüchinger, Zürich,
Frau S. Meyer, Solothurn,
Frau M. Napier, Zürich,
Frau G. Zehnder, Schaffhausen.

General co-ordination of the administrative details of the programme in Switzerland was in the hands of the Schweizerische Zentrale für Handelsförderung, Zürich. All matters regarding technical papers and works visits in Switzerland were arranged by the Verein Schweizerische Maschinen-Industrieller, Zürich.*

All arrangements for hotel accommodation and travel in Switzerland were made by Wagons-Lits/Cooks, Zürich, in collaboration with the Schweizerische Zentrale für Verkehrsförderung, Zürich. Arrangements for travel to and from Switzerland were made by Thos. Cook & Son, Ltd.

The Council of the Iron and Steel Institute would like to express their thanks to these people and organizations, and to all authors of papers and other persons in Switzerland and in England who so willingly collaborated with the Institute staff in organizing the Meeting.

The Secretary's office was open all day in the second-class waiting room on Zürich Station on 9th July, and was transferred to the Eidgenössische Technische Hochschule for the two mornings on which the technical discussions were held there.

Travel to and from Switzerland

Three lines of communication were open to the visitors from the British Isles, *viz.*, (*a*) by all-day-travel train, leaving London on Monday morning, 7th July, travelling *via* Ostend to Brussels, where the night was spent, and continuing the next day, arriving in Zürich about 11 p.m.; (*b*) by sleeping-car train, leaving London on Tuesday afternoon, 8th July, and travelling *via* Calais direct to Zürich, arriving about 11.0 a.m. on Wednesday, 9th July; (*c*) by air, travelling on Wednesday, 9th July, and taking only about 3½ hr. for the flight from London to Dübendorf, the airport of Zürich.

The visits and excursions immediately associated with the meeting proper were finished by the 15th July, so those wishing to return at once did so either by air or by all-day-travel train *via* Brussels. There were, however, two alternative excursions after the main Meeting, one to Geneva and one to Interlaken and Montreux (*see later*); those who went to Geneva returned to London by sleeping-car train and those who visited Montreux came back to England by all-day-travel train, breaking the journey in Paris, the two parties meeting on the cross-channel boat at Calais.

Detailed Programme

Short accounts of the history, development, plant, and products of the works visited were provided by the Managements, and were printed in the Detailed Programme issued to all Members and Ladies who attended the Meeting. This opportunity may be taken to express the warmest thanks of the Council of the Institute and also of the visitors to the Principals and Staffs of all the establishments visited for their charming hospitality and the freedom with which they gave full information in response to enquiries.

The Zürich Meeting

Wednesday, 9th July

From 5.0 to 7.0 p.m. a reception for Members and Ladies was given by the Canton and Municipality of Zürich in the Kongresshaus, Zürich. Dr. A. Lüchinger, Lord Mayor of Zürich, welcomed the visitors to Zürich on behalf of the Canton and City. Dr. C. H. Desch, F.R.S., President of the Institute, expressed the thanks of the Members and Ladies.

Thursday, 10th July

Following the opening of the Meeting in the Auditorium Maximum of the Eidgenössische Technische Hochschule as already described, from

* A short description of the Verein and of its organization was given on page 300 of the June *Journal*

10.15 A.M. to 12.30 P.M., while the Members were discussing technical papers, the Ladies were taken on a sight-seeing tour of Zürich. After lunch in their hotels, the Ladies boarded a steamer for an excursion on the Lake of Zürich ; tea was taken on the Au Peninsular, a favourite rendezvous on the lakeside.

At 12.30 P.M. the Members adjourned their technical session to take part in visits to one of the following establishments :

A.G. Brown Boveri et Cie, Baden.
Oederlin et Cie, Baden.
Maag-Zahnräder, A.G., Zürich.
Maschinenfabrik Oerlikon, Zürich.
Schweizerische Wagons- und Aufzügefabrik, Zürich-Schlieren.
Eidenössisch Materialprüfungs Anstalt.

Those who went to the Oerlikon Works lunched in the station restaurant—as did also those who visited the Institute for Testing Materials—and were given tea before leaving the works. Participants in the other visits were entertained to lunch by the Managements before making the tour of the works.

At 8.0 P.M. on Thursday evening, the Members and Ladies took part in a banquet at the Kongresshaus ; Professor Dr. R. Durrer, Chairman of the Reception Committee, was in the Chair. The toast of " The King " was proposed by Professor Dr. R. Durrer, and " The Swiss Confederation " by Dr. C. H. Desch.

Professor **R. Durrer** (Chairman of the Reception Committee), an Hon. Vice-President of the Institute, who proposed the toast of " The Iron and Steel Institute," said that when the possibility of a visit by the Institute to Switzerland was first suggested he was naturally very glad, but at the same time a little afraid. British metallurgists had done a great deal in the development of the production of iron and steel, and their part in the history of iron and steel was renowned throughout the world ; they had invented the most important processes used, and he feared that it might be difficult to show them sufficient of interest in the metallurgical processes and developments of Switzerland.

Switzerland had almost no raw materials, and that had forced the Swiss to look for methods and processes which people better provided for did not need to seek ; and so he hoped it would be possible to show Members some developments which arose from the very fact that the country was poor so far as raw materials were concerned. In any case they offered a very cordial welcome to Members of the Institute from Britain and also from U.S.A., Canada, France, Spain, Italy, Sweden, Holland, Belgium, Luxemburg, and Czechoslovakia.

The most important feature of such meetings as the present was the opportunity which they gave for people from many countries to meet, to exchange ideas, and to make friendly contacts. Switzerland offered a cordial welcome to all the visitors and hoped that their stay in the country would prove most enjoyable.

Nationalrat **Ernest Speiser** (President of the Verein Schweizerischer Maschinen-Industrieller) offered a cordial welcome to the Members of the Institute and their Ladies on behalf of the Swiss metallurgical and engineering industries. It was an excellent idea on their part, he said, to choose Switzerland for their Summer Meeting, and he hoped that they had found all they were looking for.

This would be the first time that many of the Members had been in Switzerland since the war. Those who had known the country before might think that little had changed, but on looking more deeply it would be found that many things had changed. The Swiss people had tried to keep pace with the times, without following every step which had been taken elsewhere. For its own inhabitants Switzerland was not a country of perpetual holiday, and for every day of pleasure they had to pay by six days of hard work.

The Swiss people, whenever, since the war, they had had the pleasure of meeting visitors from Britain again, always wished to express their admiration for the British war effort and their thanks for what Britain had done for the whole world during the dark years of war. That was especially manifest last August, when Mr. Winston Churchill spent a short holiday in Switzerland. No visitor from abroad had ever before received such a welcome, and in honouring Mr. Churchill the Swiss people wished to honour the whole British nation.

There was a long connection between the British and Swiss engineering industries. Many pioneers from Switzerland went to England to learn the secrets of their trade, and English engineers came to Switzerland to show their Swiss colleagues how to do things. When his grandfather took the initiative in promoting the first railway in Central Switzerland he called in as an expert, Robert Stephenson. Many Swiss engineering works owed their origin to the fact that in the Napoleonic wars, the textile machinery previously obtained from England could not be replaced, and no spare parts were available. This forced Switzerland to set up an industry of her own, but its English inspiration had never been forgotten.

Politically their two countries had much in common. During the war they both succeeded in maintaining democracy in full working order. If government by the people for the people was not dead today, it was due to Britain.

Dr. **C. H. Desch,** F.R.S., on behalf of the Institute, returned thanks for the hospitality offered to its Members and for the very kind remarks made by the Swiss speakers. It was, he said, a great pleasure for an Englishman to come to Switzerland, for he knew that everywhere he would find glorious scenery, attractive towns, excellent hotels and a very friendly reception. It was interesting to recall that before the great development of tourist traffic, before the days of Thomas Cook, there was a constant intercourse between England and Switzerland. The men who led it were essentially intellectuals, men like Ruskin and Leslie Stephen. The movement spread until the general public had come to regard Switzerland as one of the most attractive of holiday countries, but it would be a mistake to regard it only as a splendid holiday resort. In spite of its small size, Switzerland's position in the world's industry was extremely high ; the machinery produced by the Swiss was of a very high standard, and much had been done to develop new types of machinery.

Dr. Desch concluded by expressing both in French and in German, the thanks of the Institute for the reception afforded to its Members, and their best wishes for the success and prosperity of Switzerland and its industries.

Mrs. **Desch**, on behalf of the Ladies of the party, expressed their gratitude for the welcome accorded to them, and their pleasure in visiting Zürich. What they had seen, she said, would encourage them to go home strengthened in their determination to make their own country once again what it had been before the war.

During the banquet Professor Dr. R. Durrer announced, amidst applause, the news of the engagement of H.R.H. The Princess Elizabeth to Lieutenant Philip Mountbatten, Royal Navy. A toast was drunk.

After the banquet there was a programme of Swiss National dances by Volkstanzkreis Zürich with orchestra, Swiss folk songs by Heimatgruppe Appenzell and of alphorn-playing and flag-throwing by Franz Hug.

Friday, 11th July

The Ladies had no set morning programme. After the last technical session closed, at 12.30 P.M., the Members lunched together at the Station Restaurant and set out to visit one or other of the following works in Winterthur :

Gebrüder Sulzer, A.G.
Schweizerische Lokomotivfabrik, A.G.
J. J. Rieter, A.G.

On leaving the works the Members were motored to Kyburg where, with other visitors who had made an afternoon excursion *via* Forch, Rapperswil and Turbenthal, and yet others who had come later direct from Zürich, they were entertained to a ' peasant supper ' by the works at Winterthur. Kyburg is set amidst attractive surroundings ; its medieval Castle was used as a private residence until comparatively recently, but is now a museum filled with the furniture, household effects, arms, armour, and implements of torture such as would have been found in a fortified dwelling in the Middle Ages.

Saturday, 12th July

The Members had the choice of a morning visit to one of the following establishments :

Escher Wyss, A.G., Zürich.
Eidgenössische Technische Hochschule.

According to the printed programme no formal arrangements had been made for the Ladies all day nor for the Members during the afternoon, but as an all-day coach excursion over the Susten Pass to Innertkirchen (Power Station) and Meiringen fixed for the following day had been oversubscribed, a ' relief ' excursion was run on this day (Saturday), starting immediately after an early breakfast. The road was built by military engineers during the Second World War and was not designed for civilian needs ; it is a great feat of engineering skill and the scenery through which it passes is most magnificent.

Sunday, 13th July

On this day occurred the first major deviation from the arrangements as originally planned ; it had been found necessary to cancel the all-day coach excursion to the Susten Pass (*see* Saturday above) and substitute for it a trip to the Rigi. The visitors travelled by main-line train to Arth-Goldau ; here they transferred to the rack-railway to climb as far as Rigi-First, where lunch was taken. The return was made by the same route.

An alternative half-day outing for those who had wanted to keep the morning free was an expedition by motor to Etzelwerk, where the power station was inspected, and to Einsideln. Here is a large Monastery to which pilgrims from all parts travel in order to pray in the Chapel of the Black Virgin in the Church attached to the Monastery. Tradition says that the figure of the Virgin Mary in this shrine was originally white ; one day it was struck by lightning, and was turned black, though it was completely undamaged in all other respects ; for this reason miraculous powers were attributed to it. Another interesting feature of the Church is a collection of drawings, delineating dangers from which the donors of the pictures had been saved by the intervention of the Black Virgin.

Monday, 14th July

Members and Ladies went by train to Solothurn where they visited the works of the following companies :

Ludwig von Roll'sche Eisenwerke, A.G.
Zellulosefabrik Attisholz, A.G.
Meyer und Stüdeli, A.G.
The Langendorf Watch Co., Ltd.

Two of the von Roll works are at Klus and Choindez ; Members visiting these left the train at Oensingen. The other Members and the Ladies travelled on to Solothurn ; the Members inspected the Gerlafingen plant of von Roll or the cellulose factory, and were entertained to a country excursion and light refreshments in a village inn before returning to Solothurn for lunch. Similarly, the Ladies saw the two watch factories and something of the town of Solothurn as well. By 2 P.M. the Klus and Choindez parties had arrived in Solothurn and all the Members and Ladies were entertained to lunch in the Konzertsaal by the firms whose works they had visited. The hall in which the meal was served was beautifully decorated with evergreens, flowers, and the Swiss and British flags. Members and Ladies were welcomed by Dr.-Ing. E. Dubi, Chairman of Gesselschaft der Ludwig von Roll'schen Eisenwerke, A.G., on behalf of the firms whose works they had visited. Professor Dr. R. Durrer also welcomed the visitors to Solothurn. Dr. C. H. Desch replied in thanks on behalf of the Members and Mrs. Desch spoke in the name of the Ladies. Music was provided by a lady who sang and yodelled, and by the works brass band of the von Roll Company ; later the band appeared on Solothurn Railway Station to play the visitors away.

Tuesday, 15th July

Schaffhausen was the centre of this day's visit. The party travelled by train again, and the engine driver slowed down the train as it passed the famous Rhine Falls, thus giving the visitors a splendid view of this truly beautiful scene. In Schaffhausen the Ladies were to spend the day sightseeing, while the Members had the choice of visits to the following works :

G. Fischer, A.G.
A. J. Amsler, A.G.
Schweizerische Industrie-Gesellschaft, A.G.

It was further arranged that Members who visited works in the morning, could do a sightseeing tour in the afternoon and *vice versa*. During the morning the Ladies, and those Members who did not visit the works in the morning, visited the Schaffhausen Museum and saw a very fine collection of early German pictures. Lunch was given to the party by the works in Schaffhausen, but such was the size of the party that all could not be accommodated in a single hall, so the Members and Ladies lunched apart in company with the Swiss gentlemen and Ladies who had been their guides during the morning.

After lunch the Ladies and those Members who had visited the works in the morning embarked in a specially chartered steamer, and travelled up the Rhine as far as the picturesque little town of Stein-am-Rhein on the right bank of the river, not very far from where Lake Constance empties itself into the Rhine. In Stein the visitors were shown what had been a very old house which had twice been rebuilt after inadvertent bombing during the war—the ancient style was retained but the new materials were awaiting the hand of time to give them a more 'old-world' appearance. After an all-too-short walk round the little town the visitors re-embarked for the return to Schaffhausen by steamer and thence to Zürich by train.

Wednesday, 16th July

Officially, the Zürich Meeting finished after breakfast on this day, and a number of Members and Ladies returned home by the all-day-travel route *via* Brussels and Ostend.

Two extension programmes had, however, been prepared for those who wanted to prolong their stay and also to allow Members who wished to do so to visit works in Geneva and Ugine (France) ; notes about these visits follow.

The Interlaken and Montreux Excursion

Wednesday, 16th July

After breakfast the Members and Ladies in this party left Zürich by motor coach, to travel over the Furka and Grimsel Passes *via* Andermatt to Interlaken ; lunch was taken at Gletsch. Continuing their way over the Grimsel and down the Hasli Valley for Interlaken all went well till past Meiringen, when it was found that a landslide had fallen only a few minutes earlier and had completely blocked the road. One coach got through but the rest of the party had to complete the journey by train. The good weather experienced in Zürich had unfortunately broken, and the clouds were nearly down to Lake level, so that the lovely views were not to be seen.

Thursday, 17th July

On this day the second major departure from the original arrangements occurred. It had been planned to take the visitors on an expedition up the Jungfraujoch, travelling by train up the Lütschinen Valley to Grindelwald, whence the climb would be made by funicular railway. However, the bad weather of the previous day continued, and it was regretfully decided to cancel the trip. This day was really the only disappointment of the whole meeting.

Friday, 18th July

Starting off after breakfast, the party continued

on their way by road to Montreux ; the weather was kind again and this very pleasant journey was much enjoyed. Their destination was reached in time for lunch, so that the visitors had the afternoon and evening in which to explore this very delightful town at the eastern end of Lake Geneva.

Saturday, 19th July

The Members and Ladies set off on their return journeys home. Some left for Geneva to fly home, and the others, after an early lunch, boarded the train for Paris, where they spent the night, before continuing their journey to London *via* Calais (where they linked up with the sleeping-car party from Geneva) and Folkestone. London was reached in the early evening of Sunday, 20th July.

The Geneva Excursion

Wednesday, 16th July

This party left Zürich by train after breakfast, and reached Geneva in time for a somewhat belated lunch in their hotels. For the afternoon and evening they were left to their own devices.

Thursday, 17th July

The Members had the choice of a visit to one of the following works in the morning :

Société Genevoise d'Instruments de Physique.
S.A. Ateliers de Sécheron.
S.A. Ateliers des Charmilles.

At lunch the Members were the guests of the works visited.

The Ladies had the morning to themselves, whilst no arrangements had been made for either them or the Members for the afternoon and evening.

Friday, 18th July

Whole-day excursions had been arranged for this day. After breakfast, coaches were boarded and the whole party crossed the French–Swiss frontier near Annemasse and proceeded together as far as Bonneville. Here one group of buses carrying the Ladies and some Members turned left and, passing through Cluses Sallanches, and near St. Gervais-les-Bains, arrived at Chamonix in time for lunch—excellent packed lunches had been brought from Geneva. Chamonix stands at the foot of Mont Blanc, the highest peak in this part of the world, and the visitors had a splendid view of the mountain in all its splendour. The road to Chamonix climbs steeply in many places with frequent hairpin bends ; some of the Ladies were glad when this part of the journey was over. The return journey was varied somewhat by passing through St. Gervais-les-Bains to Mégève, the favourite winter sports centre of the district.

The second group, consisting of Members only, turned right at Bonneville and, passing through St. Jean-de-Sixt, arrived at the Col des Aravis at lunch-time ; they also had been provided with packed lunches, which were eaten in a chalet at the top of the Pass where drinks could be obtained. Continuing on their way, the party had their share of hairpin bends and narrow roads overhanging precipices on the way to La Giettaz and Fiumet ; on arrival in Ugine, the objective of their journey, they visited the works of the S.A. des Aciéries Electriques d'Ugine. Then followed an excellent and very welcome meal in the works canteen, after which the party set out on the return journey. They passed through lovely though less mountainous country *via* Faverges, past Lake Annecy to the town of the same name, and St. Julien, to cross the frontier at Perly, reaching Geneva at about eight o'clock, considerably later than the other party.

That same evening the Members and Ladies with a large number of their Swiss friends took part in a farewell supper in the Hotel des Bergues, Geneva ; Dr. C. H. Desch, F.R.S., presided. Professor Dr. R. Durrer expressed the regrets of himself and his Swiss friends that the meeting must come to an end and the visitors return to their homes, and the hope that they would be able to come again to Switzerland before long. Dr. Desch reciprocated the good wishes and gave thanks on behalf of the visitors for the excellent arrangements made for the Meeting and the warm and generous hospitality provided. Sir Andrew McCance, F.R.S., thanked Dr. Desch for all his efforts during the Meeting. Mrs. Desch expressed, on behalf of the Ladies, their thanks to their Swiss hosts and hostesses and their regret that the Meeting must come to an end. The evening concluded with the singing of " For they are Jolly Good Fellows " for Dr. and Mrs. Durrer, and of " Auld Lang Syne."

Saturday, 19th July

Some Members and Ladies flew home ; the others left in the late afternoon by sleeping-car train and joined up with the all-day-travel party at Calais.

So ended the Institute's first post-war visit to the Continent. That it was a success can hardly be in doubt ; with the exception of the change in the excursion on the 13th July and cancellation due to bad weather on the 17th, the programme was carried through as originally planned. When it is remembered that the journey covered much ground on which fighting had been going on only a little over two years previously, whereas five years had elapsed after the 1914–1918 war before the first post-war Continental meeting was held, this Meeting was felt to reflect credit on all those concerned in its organization.

Menu for Luncheon at Solothurn on 14th July
Special Summer Meeting in Switzerland, 1947

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

Practical Experience with the Use of Oxygen in Steelmaking*

By G. V. Slottman†

SYNOPSIS

A general account is given of experience in the United States with the oxygenated-oil firing of open-hearth furnaces and the use of oxygen as a bath reagent. Some twenty furnaces of 60–200 tons capacity have been equipped for oxygenated-oil firing. The effect of oxygenation on output and fuel consumption varies with the condition of the furnace and the type of charge—the greatest improvements being obtained in small furnaces of the older types and with charges requiring long melt-down periods. The use of oxygen added directly to the bath through bare pipes for controlling the bath temperature and for shortening the refining period has become standard practice in several plants making low-carbon steel.

SINCE August, 1946, when open-hearth operators in the United States first became generally interested in the use of oxygen as a combustion aid and as a bath reagent, much work of a practical nature has been done. Some twenty furnaces have been equipped for oxygenated-oil firing and numerous plants have experimented with oxygen for decarburization. This sudden burst of activity is all the more remarkable, when one considers that previous discussions on the use of oxygen in the steel industry have centred about the blast-furnace and the Bessemer converter. It was felt that the refractory problem in the open-hearth imposed a severe restriction on any use of oxygen as a means of obtaining higher flame temperatures through air enrichment. Apart from the refractory problem, however, the open-hearth furnace would appear to offer the greatest opportunity for improvement because of the many factors limiting its efficient operation, including: (1) The variable nature of the charge, both in size and analysis; (2) the complication in burner-port design caused by the need for having ports which serve both as heating-air inlets and waste-gas outlets; (3) the fact that the open-hearth heat cycle has two distinct phases, the charge and melt-down period and the refining period, each of which requires a different type of flame; and (4) the slow speed of the oxidation reactions between the refining slag and the metal bath.

The Combustion Problem

The open-hearth furnace must melt and superheat steel to a temperature some 200° F. below the softening point of the refractories, with a flame which is some 200° F. above their safe temperature limit. In actual operation a compromise must be made between high melting rates and high refractory costs, and good practice depends not so much on achieving the most efficient firing rate as on an economic balance involving the tonnage of steel which can be made before the furnace burns down. For this reason, open-hearth furnaces operate at firing rates below their optimum loading from an efficiency standpoint, and can gain in efficiency by increasing the

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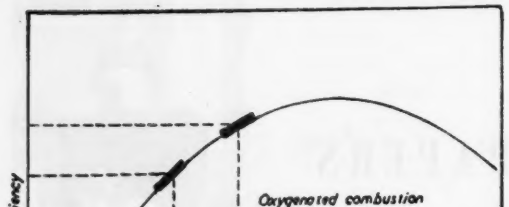

FIG. 1—Combustion efficiency *versus* firing rate

firing rate, provided that the refractory life is not unduly affected (*see* Fig. 1).

Oxygenated combustions appear to be the answer in producing a flame which can develop a maximum calorific intensity, with complete combustion in the furnace proper and at high rates of loading, without undue damage to the refractories, thus permitting of optimum loading of the combustion space. In addition, the high velocity and direction of the oxygenated-oil flame permit rapid heat transfer to the cold charge by direct contact during the charge and melt-down period.

The Principle of Oxygenated-Oil Firing

The principle of oxygenated-oil firing is illustrated in a comparison of Fig. 2, showing the normal oil–air flame, and Fig. 3, showing the oxygenated-oil flame emerging from an annular-type burner.

In the oil–air flame a slow-moving voluminous flame is formed by simple combustion of the atomized oil with preheated air from the checkers. Attempts to increase the firing rate above normal practice with this type of flame result in unburned gases leaving the combustion space and severe attack on the furnace refractories.

In oxygenated-oil firing the oil is surrounded or impinged upon by a high-velocity oxygen jet, which produces a primary combustion of the oil giving gaseous products, largely carbon monoxide and hydrogen, which then rapidly burn with the preheated air. With oxygenated-oil firing high rates of loading, up to 50% above normal, are obtainable during the charge and melt-down period, and a flame is formed with sufficient velocity to enable it to be directed at the cold scrap without materially heating the furnace lining.

Burner Design

The first burner designed for oxygen firing contained separate oil and oxygen inlets. Annular burners using central oil orifices surrounded by annular oxygen orifices were then developed. Figure 4 illustrates a typical annular-type burner. Many different variations of the oil–oxygen burner have been tried, including burners with central oxygen orifices surrounded by circular oil orifices. The disadvantage of this latter type of burner appears to be that while working well with oxygen during the melt-down period, it does not operate satisfactorily during the refining period, when a slow-moving, radiant flame covering the entire bath is desired. Present burner design appears to favour three main types—the high-velocity annular type, the low-velocity annular type, and the high-velocity burner using separate oil and oxygen orifices (the oxygen orifice being below the oil orifice). The low-velocity annular burners use oxygen velocities of some 40–50 linear ft./sec.; the high-velocity burners 400–500 ft./sec. It is too early to pass final judgment with respect to the most advantageous burner design. However, it appears that burner design involves only a minor improvement compared with the general principle of oxygenating the oil stream.

Operating Data

The experimental work has been done in furnaces of 60–200 tons capacity, with charges varying from all cold charge to 80% hot metal. Increases in the normal firing rate of from 10 to 50% have been tried, with oxygen/oil ratios varying from 10 to 35% of that theoretically required for complete combustion of the oil. The effect of oxygenation on the output and on the fuel consumption varies with the condition of the furnace and with the type of charge. With high-hot-metal practice in modern 200-ton furnaces, the production rate can be increased by 10% with

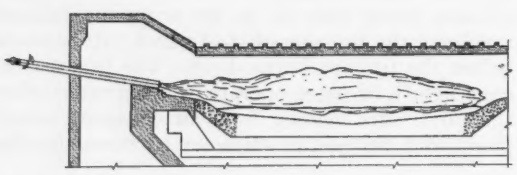

FIG. 2—Section of open-hearth furnace with oil–air flame (oil 400 gal./hr., oxygen nil, air 10,000 cu. ft./min.)

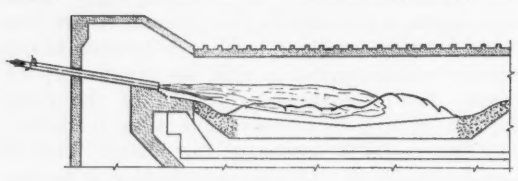

FIG. 3—Section of open-hearth furnace with oxygenated oil–air flame (oil 600 gal./hr., oxygen 800 cu. ft./min., air 8200 cu. ft./min.)

a fuel saving of 8% using some 350 cu. ft. of oxygen per ton of steel. Small furnaces of older vintage which have been increased in tapping capacity without substantial increases in the regenerative system offer the greatest opportunity for improvement. With a 50/50 scrap/hot-metal ratio, the tonnage rate increases up to 50%, and fuel savings of 25% have been made, using 700 cu. ft. of oxygen per ton of steel. All-cold-charge furnaces, with long charge and melt-down periods, show similar results.

The most effective degree of oxygenation of the oil appears to be when 25–30% of the total oxygen required for combustion is supplied as relatively pure oxygen (about 90%). However, many experiments have been made at oxygenation levels around 23%, involving the use of 25,000–30,000 cu. ft. of oxygen with 400–500 U.S. gal. of oil/hr. and have shown substantial improvement in furnace performance. It appears that the first increment of oxygen for conditioning the fuel gives the greatest return, and that a choice of the optimum operating conditions, involving fuel rate and degree of oxygenation, will depend on an economic balance in which the costs of oxygen must be balanced against the value of fuel saved and of increased productivity.

Much smaller quantities of oxygen need be supplied when using the oxygenated-oil principle than with a straight oxygen enrichment of the combustion air to achieve the desired effect of increasing the combustion rate. In addition, tests using enriched-air combustions indicate that a more diffuse flame is formed which cannot be controlled to a degree comparable to the oxygenated-oil flame during the scrap-melting period.

Control of the Oxygenated-Oil Flame

There are two factors which can be varied in oxygenated-oil combustions: (1) The firing rate; and (2) the ratio of oxygen to total oxygen, or oxygen to oil. The effect of oxygenation in increasing the firing rate with resulting increase in furnace efficiency has already been discussed. The effect of varying the oxygen/oil ratio with constant oil-firing rate will now be considered. An increase in

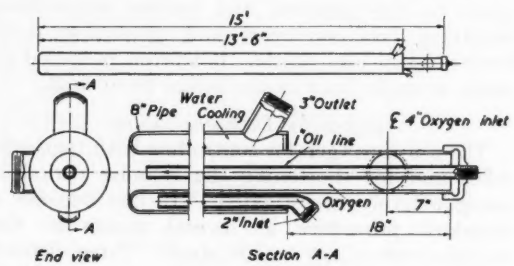

FIG. 4—Annular-type oxygen-conditioned-oil burner

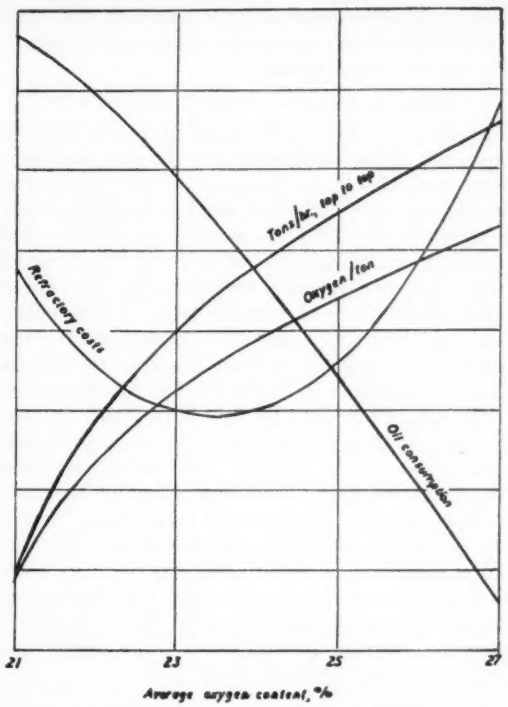

FIG. 5—Combustion tests—effect of oxygenation

the oxygen/oil ratio results in a shorter, harsher, and more sharply defined flame. The scrap-melting capacity of this type of flame appears to depend on direct contact with the charge rather than on heat transfer by radiation. Each furnace will have an optimum oxygen/oil ratio, depending on its size and shape, and a particular length of flame to give optimum melting rates. Figure 5 illustrates the general considerations influencing the choice of an optimum oxygenation of the oil. As the oxygenation is increased from 20·9%, or normal air, an increase in production is noted, with an increased expenditure in oxygen per ton of steel made. The fuel consumption per ton will fall rapidly, corresponding to the increase in furnace efficiency. Refractory costs can be expected to decrease with a moderate degree of oxygenation, since it has been found that the furnace roof is not affected by the corresponding increase in firing rate, and will then rise at higher oxygenation ratios corresponding to the extremely high flame temperatures developed. Sufficient data has been accumulated to verify the assumption that the output will rise and the fuel consumption will fall with increasing degrees of oxygenation, in accordance with the theoretical consideration that the first increment of oxygen addition will give the greatest yield. The overall economic balance involving output, oxygen consumption, oil consumption, and refractory costs must await the

long campaigns necessary to establish the exact course of the refractory-life curve in relation to the degree of oxygenation.

Radiation from the Oxygenated-Oil Flame

Some work has been done in estimating the radiation from oxygenated-oil flames compared with normal oil–air flames. Since oxygenated flames are essentially non-luminous and are more completely burned than normal oil flames, their radiation coefficients do not increase in proportion to the increase in flame temperature. The oil–air flame burns over a greater part of the hearth area, or furnace combustion space, and shows little variation in its passage through the furnace. The oxygenated-oil flame reaches its maximum radiating power at the first door, and is some 20–30% higher on an arbitrary radiation scale than the oil–air flame. Its radiation index diminishes rapidly, indicating a rapid absorption of heat by the charge, and falls below that of the oil–air flame at the outgoing end. For moderate increases in firing rate (up to 20% above normal) the waste gases leaving the furnace are apparently at a lower temperature than in normal firing, where combustion takes place slowly over the entire length of the furnace.

Use of the Oxygenated-Oil Flame

Standard practice is to start oxygenation of the oil stream when sufficient scrap has been charged to absorb heat rapidly from the flame. The oil-firing rate is raised some 15–50% above normal, and the oxygen and air flow adjusted to give the desired degree of oxygenation. The oxygen and air flows are readjusted where necessary to correspond with variations in the oil-firing rate as required by the furnace condition. When scrap can be charged without interruption no change in the firing rate is generally required. At this period of the heat the roof temperature is considerably below the permissible maximum, and is of the order of 2500–2850° F. The oxygenation is continued until the hot metal has been added, or until the bath is melted flat, at which time the oil-firing rate is generally reduced and the normal oil–air flame established. Some work has been done with the oxygenated-oil flame after melt down and the consensus of opinion is that it is not as effective during this period as the more voluminous and radiant normal flame. It has been used for short periods during slag foaming and may have some application in beating down secondary slag foaming in high hot-metal practice. It has also been used toward the end of a furnace campaign, when the checkers are fouled, to obtain a sufficiently high firing rate to heat the bath rapidly to tapping temperature. It is probable that for this application oxygenation of the combustion air will prove more effective than the use of oxygen through the gun-type burner.

Effect on Refractories

With moderate increases in the rate of firing, no difficulty with excessive roof wear has been experienced. It is more than probable that the cost of roof refractories per ton of steel will actually be lower than normal, corresponding to the increased production rate. The major difficulty reported appears to involve excessive slag accumulations on the walls of the downtakes, and more rapid fouling of the checkers. The slag accumulation appears to result from the lower waste-gas temperatures with oxygenated-oil firing, which permit slag to solidify on the downtake walls. Estimates of the extent of this deposit indicate that it is as great with 85 oxygen heats as with 115 normal heats. The answer to this problem appears to lie in a higher rate of oil firing, in order to maintain a given minimum waste-gas temperature, and in the use of basic end walls and downtakes to prevent stringer formation. The use of oxygenated-oil firing will give impetus to the more extensive use of basic refractories in general, since the large increases in production rates which are possible will offset the higher cost.

Industry-Wide Application

The work which has been done to date with oxygenated combustions has been entirely experimental, and has been confined to one or two furnaces at each plant. The possibility of extending this application to general melting-shop practice depends on two factors, *viz.*, oxygen supply and scrap-charging facilities. The consumption of oxygen has been found to vary from 0·01–0·03 tons per ton of steel with hot-metal practice to 0·03–0·05 tons per ton for furnaces working all cold charges. An industry-wide application of oxygen firing in America would require the production of at least 2,000,000 tons of oxygen per year. The present productive capacity of the oxygen industry is some 750,000 tons per year. An even more serious consideration is the problem of rapidly charging a long line of open-hearth furnaces to keep pace with the accelerated melting rate. Much thought is being given to this problem and various suggestions involving belt conveyors and removable roofs have already been made. It is even proposed to make a single door of the entire front wall.

Oxygen for Decarburization

The use of oxygen for controlling bath temperatures and for shortening the refining period is being actively investigated. It has become a standard procedure in several plants in the manufacture of low-carbon steels. Three distinct applications show great promise, namely (1) in the manufacture of very low-carbon steels, (2) in

accelerating the rate of the normal ore reaction in higher-carbon steels, and (3) in hastening the lime boil. Standard practice involves the use of bare pipes, ¾–1 in. in dia., with oxygen pressures of 90–150 lb./sq. in. and flow rates of 35,000–60,000 cu. ft./hr. Pipe life of 10–40 min. per pipe has been obtained. The use of a rack to hold the pipe appears particularly advantageous in obtaining long pipe life, since the pipe can be properly positioned and slowly advanced into the furnace. Even in high-carbon heats (above 2%), where short pipe life (2–3 min.) has been reported, pipe life up to 40 min. has been obtained in this way. The use of water-cooled pipes is not considered desirable because of the additional equipment which must be moved across the busy charging floor. Some consideration, however, has been given to lancing through openings in the back wall to avoid interruptions from the charging-floor traffic.

Oxygen Consumption

The consumption of oxygen per 0·01%-ton (0·2 lb.) of carbon removed has been found to vary with the bath carbon content, the rate of oxygen flow, and the volume and basicity of the slag. Theoretically 3·2 cu. ft. of oxygen are required to oxidize 0·2 lb. of carbon to carbon monoxide. In carbon ranges above 0·5%, and with an oxidizing slag present, the oxygen consumption is as low as 2 cu. ft. per 0·2 lb. of carbon removed, increasing rapidly below 0·20% carbon, to 6 at 0·15%, 9 at 0·10%, and 25 at 0·05% carbon. The oxygen content of the slag slowly increases as the carbon falls to about 0·06%, and then increases rapidly as the carbon is eliminated below this level. Since only moderate quantities of oxygen are required for decarburization as compared with combustion, more plants have experimented with it than with oxygenated-fuel firing.

In making low-carbon steels, carbon has been

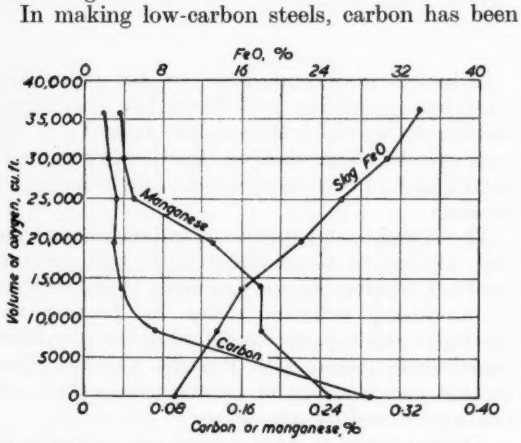

FIG. 6—Course of oxygen boil in making low-carbon steel

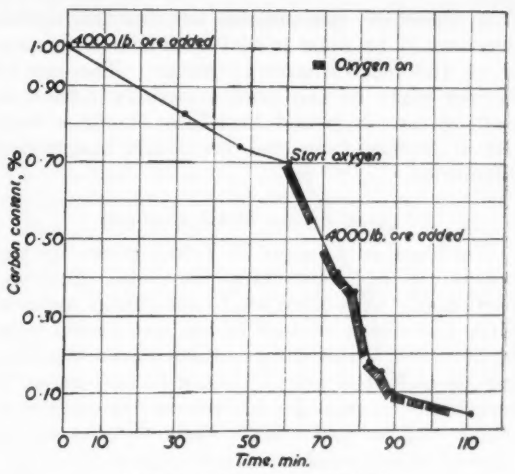

FIG. 7—The ore/oxygen boil

reduced from 0·15% to 0·03% in a 90-ton heat, by using some 12,000 cu. ft. of oxygen, *i.e.*, 130 cu. ft. per ton of steel. High rates of carbon elimination have been obtained, carbon having been reduced from 0·40 to 0·08% in small furnaces in 2½ min., a rate approaching that of Bessemer converter operation. Time savings of 1–3 hr. in the manufacture of low-carbon steels have been reported and it is in this field that the process appears to have the most immediate application. The course of an oxygen boil in a low-carbon heat is shown in Fig. 6.

Use of Oxygen for Heating the Bath

In higher-carbon ranges, and particularly with high hot-metal practice, considerable time saving can be expected, particularly with heats which are slow in absorbing ore into the slag (probably because of too low a bath temperature). A combination oxygen/ore boil has been used with some success to speed up carbon elimination (*see* Fig. 7).

In addition, the possibility of rapidly increasing the bath temperature by the use of oxygen appears to offer the furnace operator a control over the refining cycle which has been lacking in the past. Some work has been done using oxidizing mixtures of ore and oxygen blown into the bath, and on combining an oxygen blow with additions of ferrosilicon to increase the bath temperature rapidly. The practical limit to the rate of oxidation of carbon in the open-hearth appears to depend on the amount of blowing of the slag against the furnace lining which is permissible, and the ability of the waste-gas ducts to pass the volumes of carbon monoxide evolved from the bath. Considerable fume is produced when using oxygen during the lime boil with high-hot-metal charges and there is a severe action on the furnace refractories due to the violent activity of the bath.

It is, therefore, questionable whether this operation should be done in the open-hearth furnace or at the blast-furnace or mixer. The use of oxygen early in the heat materially assists in melting the scrap and hastening the lime boil, but it suffers from the previously mentioned difficulties.

Control of Hot-Metal Analysis

Considerable thought is being given to the possibility of controlling hot-metal analysis, particularly with reference to the silicon content. Since the silicon content of hot metal even from large mixers varies widely, causing corresponding variations in the weight of slag to be formed, it represents a variable in open-hearth operation which can be controlled. Reducing the silicon content of hot metal to a given analysis by oxygen addition and removing the slag before pouring the metal into the open-hearth appears to offer possibilities in the way of controlling the refining-slag composition and in reducing the amount of deoxidizing additions. When blowing hot metal with oxygen, some loss of manganese is experienced, the effect of which on desulphurization remains to be investigated.

No operating difficulties have been experienced with an oxygen blow either in the furnace or in the ladle, when reasonable precautions were taken to control the metal temperature by suitable ore or scrap additions, and when the degree of boil was limited to that which would not damage the furnace refractories. In adding oxygen to the hot-metal ladle care must be used to prevent the formation of a crusted slag, which will prevent the escape of the gases formed. The effect of oxygen on the furnace bottom in low-carbon steels has been no worse than with normal ore practice, and the shortened period of refining during which the furnace must be kept at very high finishing temperatures has been found to increase the refractory life of the furnace lining.

Sulphide Penetration in the Carburization of Steel*

By A. Preece, M.Sc., F.I.M.,† and K. J. Irvine, B.Sc.†

SYNOPSIS

The mechanism of sulphide penetration into steel during carburization has been demonstrated by experiments in which suitably coated specimens of Armco iron have been exposed to carburizing mixtures of carbon monoxide and carbon dioxide. By adjusting the gas mixture in contact with specimens, deep-seated inclusions of iron sulphide have been converted into iron oxide. Iron sulphide inclusions have also been converted into manganese sulphide by prolonged treatment at 1000° C. The results have also shown interrelated effects between carbon, sulphur, and oxygen which may be of significance in the segregation and homogenization of steel castings.

I—INTRODUCTION

In a previous paper[1] the authors described the formation of a band of iron sulphide some distance below the surface of a specimen of cast iron. The structure resembled that obtained in commercially malleablized cast iron when the defect known as "peeling" occurred.

It was shown that on exposing the iron at high temperature to a carbon-monoxide/carbon-dioxide atmosphere containing sulphur, a scale which contained iron sulphide formed on the surface. This iron sulphide could be made to move into the metal by a subsequent exposure of the specimen to a carburizing atmosphere.

Although it was possible to lay down the conditions governing peel formation, the actual mechanism by which the sulphide moved into the metal was by no means clear. Further experiments have therefore been carried out to investigate this problem.

The experimental apparatus and technique were very similar to those described in the previous paper. Considerable use was made of the method of producing artificial scales by coating the specimen with a paste consisting of the powdered constituents mixed with Bakelite varnish, since in this way coatings of known composition are easily produced on the surface of the metal.

The experiments were carried out primarily to investigate the action of carbon monoxide in

* Received 14th May, 1947.
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causing the sulphide to move into the metal, and also to explain the various aspects of the structure, namely, the definite band formation and its association in some cases with an intercrystalline network of oxide or silicate.

II—Previous Work

An examination of the literature showed very few references to the diffusion of sulphur in iron, and certainly no indication of any massive penetration of iron sulphide. There have been occasional references, however, concerning both the malleablizing process and pack carburizing where, in certain special cases, intense penetration of iron sulphide has occurred. In both these instances the packing medium contained sulphur, and in conjunction with the carburizing atmosphere produced a penetration.

A series of papers by Campbell[2–4] gives an account of a number of experiments which showed that iron sulphide could move through steel very rapidly at temperatures of the order of 1200° C. Though his experimental technique was not entirely satisfactory, his conclusions were supported by the work of Arnold and M'William,[5] who investigated the diffusion through iron of a number of elements, including sulphur. A feature of both these investigations was that the diffusing substance left little trace of its passage through the metal. Hindley[6] showed that diffusion of sulphur into steel could occur at 800° C. from a layer of iron sulphide produced on the surface by heating specimens in an atmosphere of hydrogen sulphide. It was shown that the carbon was displaced towards the centre of the specimen by the inward diffusion of sulphur.

Bramley and his co-workers[7] carried out experiments using hydrogen containing small quantities of hydrogen sulphide as the heating atmosphere. The temperature employed was 1000° C., and special care was taken to avoid the formation of a sulphide scale on the surface. They found that absorption of sulphur occurred, and that the subsequent diffusion followed the ordinary diffusion laws. They noted that the rate of diffusion was decreased by the presence of carbon in the specimen. They also showed that the original sulphur content of the specimen had a pronounced effect upon the rate of diffusion of carbon. The rate of diffusion of sulphur in these experiments was very small, being approximately three hundred times smaller than that of carbon.

III—Experimental Results

Since it had been previously shown that the chemical composition of the irons had an important influence on the amount and rate of sulphide penetration, Armco iron was chosen for the initial experiments of this further investigation, in an attempt to reduce the variables of composition to a minimum.

The general procedure was to coat the specimen of metal with iron sulphide (or the particular mixture of constituents being investigated), powdered and made into a paste by admixture with Bakelite varnish. The paste was hardened by polymerization before exposing the specimen to the various gaseous atmospheres at high temperatures.

(1) *The Penetration of Iron Sulphide into Armco Iron*

The structure obtained by treating a specimen of Armco iron coated with iron sulphide in an atmosphere of carbon monoxide is shown in Fig. 4. In this case the coated specimen was treated for 20 hr. at 1000° C. The layer of iron sulphide is shown well inside the metal with very little sulphide between this layer and the surface of the specimen. This clear zone was a particular feature in these experiments, for, apart from the few isolated particles of iron sulphide, there was an absence of non-metallic inclusions. It would appear that these non-metallics were either dissolved by the advancing iron sulphide, or pushed forward by it, as indicated in Fig. 5.

On etching the specimen shown in Fig. 4, the layer of iron sulphide was found to be at the inner limit of carburization. This is shown in Fig. 6, where it will be seen that the concentration of carbon in the carburized zone is maintained at approximately eutectoid composition throughout. In the absence of a sulphide coating the carburization showed the normal concentration gradient. After long-time treatments it was possible to compare the depths of penetration of carbon in both cases, and, allowing for the discrepancy caused by the concentration gradient, which is not found in the specimen coated with sulphide, the depth of penetration was approximately the same.

After treatment in the carbon monoxide at 1000° C. the black powdery remains of the paste contained bright metallic globules and the surface of the specimen was covered with a bright layer which, from its general appearance, had been molten during the experiment. As the melting point of iron sulphide is 1193° C. there must have been some reaction taking place which resulted in a product with a melting point below 1000° C. Further examination of the bright globules remaining in the paste showed that they consisted of a mixture of iron and iron sulphide; the appearance under the microscope can be seen in Fig. 7. This sulphide complex could be produced merely by heating iron sulphide in the carbon monoxide atmosphere at 1000° C., indicating that the iron/iron-sulphide mixture was produced by

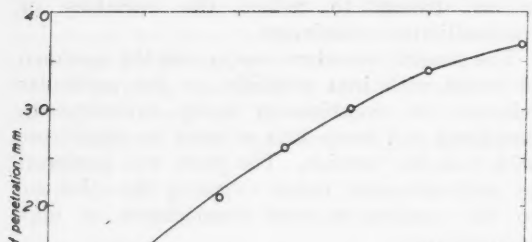

FIG. 1—Effect of time on the depth of penetration of iron sulphide into Armco iron

volatilization of sulphur. The iron/iron-sulphide diagram shows a eutectic which melts at 985° C., which would account for the molten layer at the temperature of the experiment. Heating for 5 hr. was sufficient to form the eutectic, and further heating then increased the amount of iron present. Thus for a limited time during the experiment the iron would be covered with the molten eutectic of iron and iron sulphide.

It seemed, therefore, that the formation of this eutectic was an essential requirement for penetration, *i.e.*, it was the molten iron/iron-sulphide eutectic, as such, which moved into the metal. In general, the sulphide layer present in the iron showed no eutectic structure. This eutectic is rarely observed in the presence of excess iron ; it was found in a few cases, however, as in Fig. 8, but in these instances the presence of an exceptionally large quantity of the complex might explain the retention of the structure. The eutectic may also be retained if the specimen is quenched in water from the temperature of treatment ; an example of this can be seen in Fig. 9.

(a) *Effect of Temperature*

Further evidence that the penetrating substance was the molten eutectic was obtained by carrying out experiments at slightly below 985° C., the melting point of the eutectic. It was found that no penetration took place at 980° C. or below, but that at 990° C. the penetration was comparable to that at 1000° C.

Experiments were also carried out at higher temperatures, intervals of 10° C. up to 1200° C. being adopted. The results were rather remarkable in that the same depth of penetration was obtained at each temperature ; this unusual feature is considered later in the paper.

(b) *Effect of Time*

The rate of penetration of iron sulphide under these conditions was very rapid. Even in as short a time as 1 hr. definite penetration was noticeable. As the time of treatment increased, the rate of penetration decreased. From Fig. 1 it will be seen that the form of the graph is parabolic and does in fact follow the equation $D = KT^2$ very closely. As the depth of penetration increased, the sulphide layer became less definite, tending to split up into separate particles.

(c) *Effect of Atmosphere*

The experiments carried out so far had shown interesting results. The formation of a eutectic on the surface was essential. In addition, the penetration was associated with an atmosphere high in carbon monoxide. In order to ascertain whether this was a unique action, experiments were carried out with other atmospheres. It was essential to ensure that the necessary molten eutectic was formed on the surface of the specimen. Consequently, in addition to coatings of iron sulphide, samples of the eutectic were prepared from iron sulphide and iron powder, and also by exposing iron sulphide to carbon monoxide. Specimens were then coated with these materials as in previous experiments. Hydrogen and nitrogen, respectively, were used as the heating atmosphere, but in no case was any significant penetration obtained. In view of the precautions taken to ensure the presence of the molten eutectic, it seems reasonable to conclude that only carbon monoxide is effective in causing sulphide penetration. It must be emphasized that this refers to the penetration of iron sulphide as such. Bramley[7] has shown that normal diffusion of sulphur takes place from a hydrogen atmosphere containing hydrogen sulphide, but this is a slow process, and for the duration of these experiments—namely 20 hr.—would be negligible.

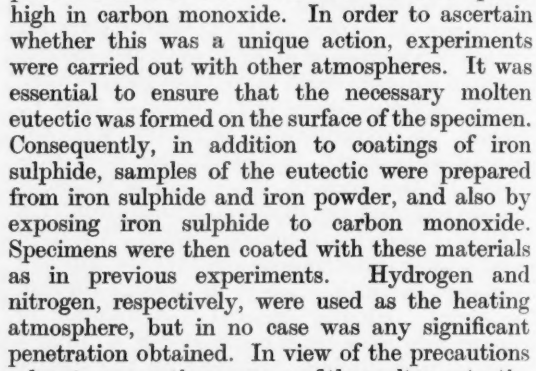

FIG. 2—Movement of molten sulphide in iron

(d) *Suggested Mechanism*

From the results described it is clear that the movement of the sulphide is due to the carburization of the iron, and the carbon monoxide atmosphere is important only insofar as it is a carburizing medium. The movement of the molten sulphide is undoubtedly caused by a difference in the carbon concentration in the iron on each side of the sulphide layer. This may be made clearer by reference to Fig. 2.

Progressive carburization of the iron can only occur by the transport of iron through the molten sulphide layer. Solution of carbon occurs at the surface of the specimen, and, as carbon cannot dissolve in iron sulphide, there is a continual absorption of iron from the sulphide by the high-carbon layer. Solution of iron takes place at the inner face of the sulphide layer, and this results in a gradual movement of the latter towards the centre, leaving carburized iron behind it. The iron present in solution in the sulphide is sufficient to render it molten at 1000° C.

An almost identical mechanism is found in the oxidation of iron in furnace atmospheres containing appreciable quantities of sulphur. On the surface of the oxidizing metal a sulphide layer is built up between the oxide and the metal, and on the inner side of this sulphide iron is dissolved while on the exterior iron is oxidized to form iron oxide.

The fact that increasing the temperature above 990° C. has no effect on the rate of penetration is interesting, because it supports ideas which have been put forward with respect to carburization in carbon monoxide atmospheres. Experiments reported by Bramley and Jinkings[8] show that as the temperature increases, the depth of penetration increases, but the concentration of carbon at the surface decreases.

It appears that there are two distinct processes involved, namely, (*a*) a surface reaction in which carbon is taken into solution in the iron, and (*b*) diffusion of this carbon into the metal.

Although the second process is speeded up by increase in temperature, the indications are that the first tends to a maximum. This is substantiated by the experiments described in this section, for where the specimen contains a sulphide layer the depth of carburization remains constant over a 200° C. temperature range.

(2) *The Effect of Iron Oxide Additions to the Sulphide Coating*

It has already been shown that in the malleablizing process for cast iron (where this abnormal penetration of sulphide was first encountered), the scale formed on the iron consists of an iron-oxide/iron-sulphide mixture which varies in composition with the oxygen pressure of the atmosphere. In order to determine whether the presence of oxide in the surface coating could influence sulphide penetration, a complete range of oxide–sulphide mixtures were prepared and applied to specimens of Armco iron, which were then treated in turn in carbon monoxide at 1000° C. for 20 hr., as in previous experiments.

With coatings containing more than 50% of FeO there was a slight amount of intercrystalline oxidation but no sulphide penetration. Less than 50% of FeO produced a slight degree of sulphide penetration, which increased as the proportion of iron oxide decreased, reaching a maximum with a 75% FeS/25% FeO mixture. Further decrease in the amount of iron oxide led to reduced sulphide penetration, but an abrupt increase occurred again when the coating was 100% FeS. Sulphide penetration attained a maximum, therefore, both in amount and depth, with two different compositions of surface coating, namely (i) 100% FeS, and (ii) 75% FeS and 25% FeO. The degree of penetration with these two coatings was roughly equal and in each case appeared as a layer of iron sulphide. There was no trace of any oxide–sulphide eutectic in any of the specimens which had been coated with the oxide–sulphide mixture.

It might be thought that the oxide–sulphide coatings were simply reduced by the carbon monoxide to the iron/iron-sulphide eutectic and that penetration followed, as in previous experiments where no oxide had been used. The iron oxide definitely exerted an effect, however, as it was found that penetration of sulphide could be obtained from oxide–sulphide coatings at temperatures as low as 960° C., whereas in the absence of iron oxide the lowest temperature for penetration was 980° C. It is highly probable, therefore, that with coatings of this type the penetrating layer of sulphide contains oxygen, which lowers its melting point, even though no oxide is visible under the microscope.

(3) *The Influence of Carbon Dioxide Additions to the Atmosphere*

The effect of varying the carburizing nature of the atmosphere was next examined. This was carried out by adding carbon dioxide to the carbon monoxide, and a range of atmospheres from 100% CO to 70% CO/30% CO_2 was chosen. Carbon dioxide additions beyond 30% were not used, as they resulted in surface oxidation of the specimens. Two series of experiments were carried out, one with specimens coated with iron sulphide, and the other with 75% FeS and 25% FeO.

(a) *Iron Sulphide Coatings*

In the experiments on the iron sulphide coatings, with 30% of CO_2 in the atmosphere all trace of the coating was removed, and a slight amount

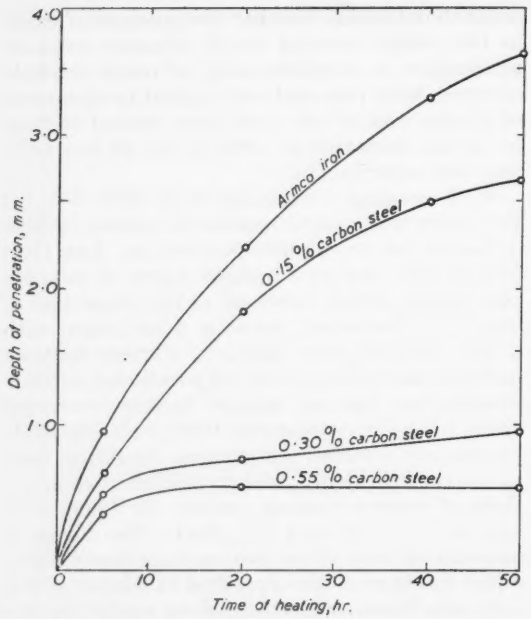

FIG. 3—Depth of penetration of iron sulphide into Armco iron and steels of varying carbon content

of surface oxidation occurred. With less than 30% of CO_2 surface oxidation ceased, but no sulphide penetration was obtained until the carbon dioxide was reduced to below 15%. As might be expected, carburization and sulphide penetration were initiated simultaneously. Both these effects were, however, slight and remained so until the carbon dioxide content was brought down to 2 to 3%, when both carburization and sulphide penetration became appreciable and greatly increased as the carbon dioxide content was further reduced to zero.

(b) *Iron-Oxide/Iron-Sulphide Coatings*

Similar results were obtained in the experiments on the iron-oxide/iron-sulphide coatings, in that no carburization or sulphide penetration occurred with more than 15% of CO_2 in the gas mixture. At this concentration a slight degree of carburization and penetration became evident, but the penetrating sulphide contained iron oxide, as shown in Fig. 10. As the percentage of carbon dioxide was further decreased, the oxide component of the penetrating mixture became less and finally disappeared, and only iron sulphide was visible in the specimens.

From these results it would appear that the oxide–sulphide eutectic is stable only in an atmosphere containing more than about 15% of CO_2. Such an atmosphere is not sufficiently carburizing to produce a large penetration of sulphide. In atmospheres which are high enough in carbon monoxide to carburize the iron, no iron oxide remains on the surface, and the penetrating substance is iron sulphide. It is evident from previous results that the sulphide will, however, contain some oxygen in solution.

(4) *The Effect of Additional Elements in the Iron*

(a) *Influence of Carbon*

A series of steels the carbon content of which increased from 0·15 to 0·90% was used to investigate the influence of carbon. The specimens were chosen so that apart from the carbon content the compositions were similar. The steels were coated with iron sulphide and treated in carbon monoxide at 1000° C. for varying times. The analyses of the steels are given in Table I, and the depth of penetration for the various steels, plotted against time, is given in Fig. 3. For comparison purposes results obtained with Armco iron are also included.

It will be seen from Fig. 3 that penetration was less with the 0·15% carbon steel than with Armco iron. It was also noted that the sulphide was more dispersed, as can be seen in Fig. 11. This tendency towards dispersion became more pronounced in the higher-carbon steels and was accompanied by a corresponding decrease in penetration. While the sulphide layer remained continuous it constituted an effective barrier to

TABLE I—*Analyses of the Irons and Steels Used in the Experiments*

Specimen No.	Carbon, %	Silicon, %	Manganese, %	Sulphur, %	Phosphorus, %
(a) *Influence of Carbon*					
1	0·15	0·11	0·70	0·03	0·035
2	0·30	0·20	0·78	0·03	0·04
3	0·55	0·25	0·70	0·025	0·03
4	0·75	0·25	0·65	0·03	0·035
5	0·90	0·25	0·60	0·03	0·035
(b) *Influence of Manganese*					
6	...	0·57	0·16	0·062	0·096
7	...	0·57	0·35	0·062	0·096
8	...	0·57	0·66	0·062	0·096
9	...	0·57	0·87	0·062	0·096
10	...	0·57	1·34	0·062	0·096
(c) *Influence of Silicon*					
11	...	0·54	0·39	0·099	0·083
12	...	0·69	0·39	0·099	0·083
13	...	0·88	0·39	0·099	0·083
14	...	1·17	0·39	0·099	0·083
15	...	1·72	0·39	0·099	0·083
(d) *Influence of Sulphur*					
16	...	0·73	0·22	0·165	0·05
17	...	0·73	0·22	0·193	0·05
18	...	0·73	0·22	0·241	0·05
19	...	0·73	0·22	0·281	0·05
20	...	0·73	0·22	0·346	0·05
21	...	0·73	0·22	0·374	0·05

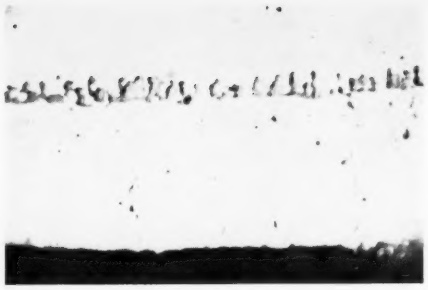

FIG. 4—Sulphide layer produced in Armco iron coated with iron sulphide and exposed to CO for 20 hr. at 1000° C. × 40

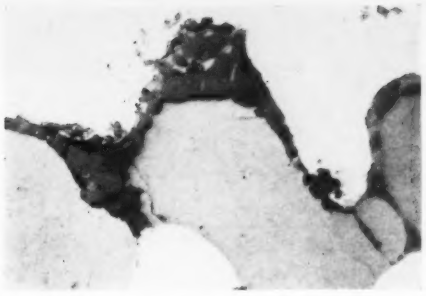

FIG. 5—Inclusions being carried forward by sulphide layer × 600

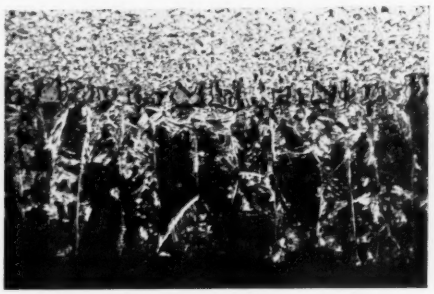

FIG. 6—Same specimen as in Fig. 4, etched with nital to show carbon concentration behind sulphide layer × 40

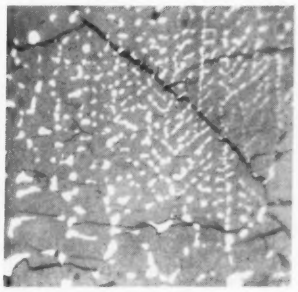

FIG. 7—Iron/iron-sulphide eutectic produced on surface of iron × 500

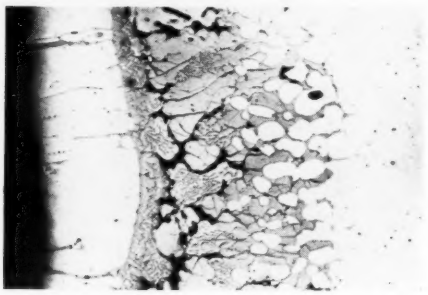

FIG. 8—Iron/iron-sulphide eutectic inside the Armco iron × 40

FIG. 9—An isolated globule after water-quenching specimen from 1000° C., showing retention of iron/iron-sulphide eutectic × 1500

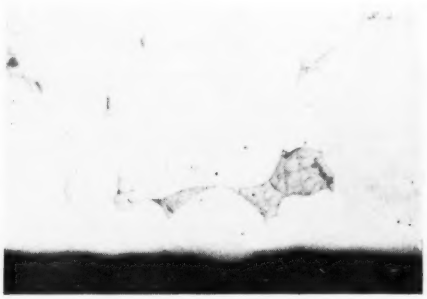

FIG. 10—Slight penetration of oxide–sulphide eutectic in an 85% CO/15% CO_2 atmosphere × 160

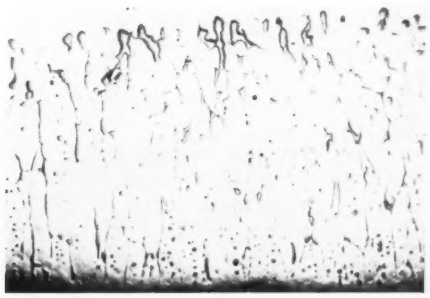

FIG. 11—Dispersed nature of penetrating sulphide in 0·15% carbon steel × 40

(Micrographs reduced to four-fifths linear in reproduction)

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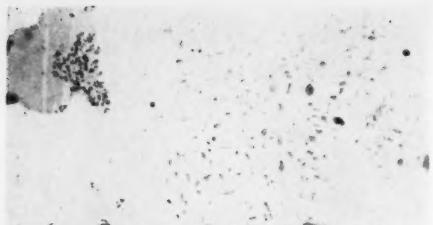

FIG. 12—Fine dispersion of sulphide particles associated with the larger masses × 500

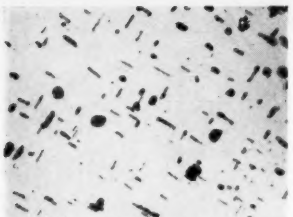

FIG. 13—Same dispersion of sulphide particles as in Fig. 12, showing the characteristic elongated shape × 1200

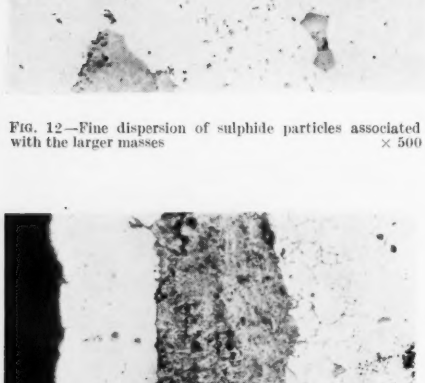

FIG. 14—Large sulphide layer obtained with 1·35% silicon iron × 40

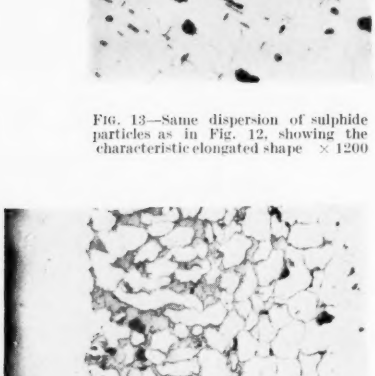

FIG. 15—Sulphide associated with intercrystalline network of silicate when using coating containing iron oxide × 40

FIG. 16—Sulphide layer after 50 hours' exposure to 75% CO/25% CO_2 atmosphere. Iron oxide visible × 500

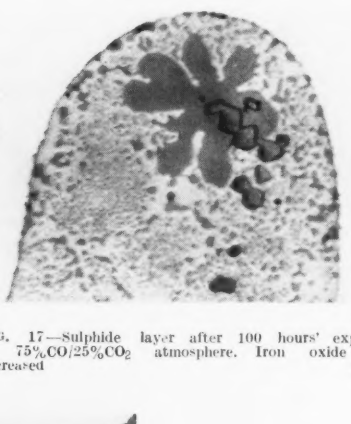

FIG. 17—Sulphide layer after 100 hours' exposure to 75%CO/25%CO_2 atmosphere. Iron oxide has increased × 500

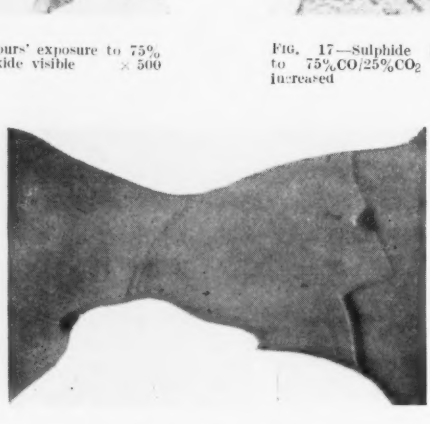

FIG. 18—Sulphide layer after 200 hours' exposure to 75%CO/25%CO_2 atmosphere. Layer completely converted to iron oxide × 500

(Micrographs reduced to four-fifths linear in reproduction)

carbon and maintained its position in front of the advancing carburized layer. Once this continuity was lost the carbon diffused beyond the sulphide and the tendency for the latter to move forward disappeared. With the 0·55% and higher carbon steels dispersion of the continuous sulphide layer was so rapid that penetration ceased after the first few hours.

As might be anticipated, the eutectic character of the penetrating material was lost as soon as it became dispersed, as the individual masses of sulphide were then surrounded by iron of the same carbon content. With Armco iron the sulphide was able to maintain its molten state only by continually dissolving iron, free from carbon. In the high-carbon steels, however, this is not possible, and the continual pressure of carbon around the isolated sulphide masses would tend to absorb the iron in solution in the sulphide, rendering the latter solid and hence preventing any further penetration. No eutectic was observed in these specimens even with the most drastic quenching.

An interesting feature with specimens in which sulphide dispersion had occurred was that around each of the large masses of sulphide there was a concentration of extremely small particles, as in Figs. 12 and 13; these photographs show the characteristic shape of these particles, which were elongated and generally at right angles to each other. This structure was more pronounced as the original carbon concentration increased. The particles were globular with the 0·15% carbon steel, but became elongated in higher-carbon specimens. From the colour of the particles it was concluded that they were manganese sulphide.

A specimen of 0·75% carbon steel was treated to obtain sulphide penetration and then quenched in water from the temperature of the experiment. Examination of this specimen showed the same concentration of small sulphide particles, though the dispersion was rather finer. It would seem, therefore, that though these particles were undoubtedly formed by precipitation on cooling, the process was extremely rapid. The large sulphide globules were mainly iron sulphide, but contained some manganese sulphide. Treatment at 1000° C. for 200 hr., however, was sufficient to convert the massive iron sulphide to manganese sulphide.

(b) *Influence of Manganese*

The analyses of the irons used in the experiments upon the influence of manganese are included in Table I. The manganese content varied from 0·16 to 1·34%. The irons were completely decarburized in hydrogen, coated with iron sulphide, and treated in carbon monoxide in the usual manner. It will be realized that it was

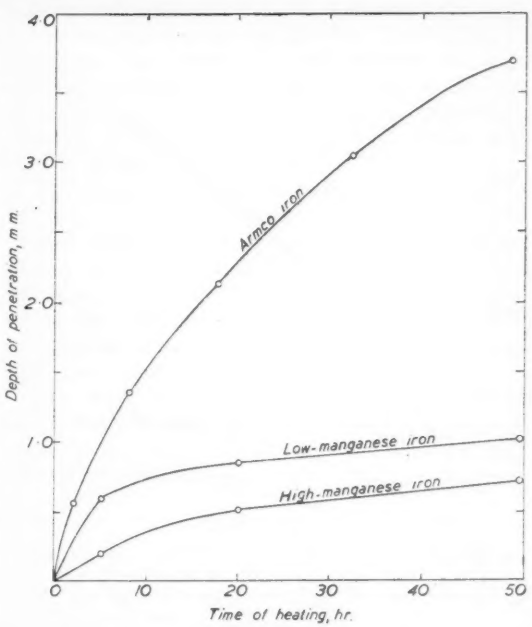

FIG. 19—Depth of penetration of iron sulphide into irons of varying manganese content

not possible in these experiments to dissociate completely the effect of other elements, notably silicon. As, however, the compositions—apart from the manganese content—were very similar, any differences in the series may be attributed to manganese.

The general effect of increasing the manganese content was to decrease the rate of penetration of iron sulphide. This was most noticeable in the experiments of short duration. After 5 hr., for example, the penetration on the lowest-manganese iron was three times as deep as in the high-manganese iron. During the first few hours the sulphide layer was continuous, with the carbon concentrated behind it. Longer treatments caused the layer to break up, allowing the carbon to diffuse beyond it, and penetration of the sulphide then virtually ceased; this can be seen from the curves in Fig. 19. In the experiments of long duration the carbon had advanced beyond the sulphide, but the depth was the same in each of the irons. Thus, although the presence of manganese in the iron has an effect on the penetration of iron sulphide, it does not appear to influence the rate of diffusion of carbon.

Even in the early stages, when the sulphide layer was continuous, it was found that although the non-metallics were carried with the layer, there was no difference in the manganese content of the metal on either side of it. In agreement with this view was the observation that although small

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FIG. 20—Depth of penetration of iron sulphide into irons of varying silicon content

amounts of manganese sulphide were associated with the iron sulphide, the proportion of the former did not increase with the manganese content of the iron. There was also no evidence of progressive absorption of manganese by the sulphide as it moved deeper into the metal.

(c) *Influence of Silicon*

The irons used for the investigation of the influence of silicon are listed in Table I. Again the specimens are similar in composition, with the exception of the element being considered.

As shown in Fig. 20, silicon decreased the penetration of the sulphide in approximately the same way as manganese, but the amount of sulphide which was absorbed by the metal was found to be very much greater. The sulphide band produced in a high-silicon iron is shown in Fig. 14, where the increased thickness of the sulphide layer is clearly demonstrated. With bands as thick as these, disruption did not occur as readily as in the irons containing high carbon or manganese.

When specimens of high-silicon iron were coated with an iron-oxide/iron-sulphide mixture and treated in carbon monoxide, the sulphide penetration was accompanied by the formation of an intercrystalline network, presumably of iron silicate. This structure is shown in Fig. 15, and the formation of silicates further substantiates the claim made earlier, *viz.*, that the penetrating sulphide can carry oxygen in solution.

(d) *Influence of Sulphur*

For the investigation of the influence of sulphur, irons containing from 0·165 to 0·374% of sulphur were treated in the usual way, but in each of the irons the depth of penetration was the same. In the case of the high-sulphur irons, the large amount of manganese sulphide originally present in the iron, being gathered up by the advancing layer of iron sulphide, tended to make this layer seem larger than in the low-sulphur irons. Apart from this, however, the increasing content of sulphur exerted no effect.

(5) *The Removal of Sulphide from the Deep-Seated Iron Sulphide Layer*

In the paper on peel formation[1] the authors showed that the iron sulphide layer could be converted to iron oxide by heating the specimens for prolonged periods in suitable mixtures of carbon monoxide and carbon dioxide. Further experiments along these lines have shown the intermediate stages in this conversion.

Specimens of Armco iron were coated with iron sulphide and treated in carbon monoxide to produce the usual deep-seated layer of iron sulphide. The specimens were then exposed for varying lengths of time to a 75% CO/25% CO_2 atmosphere, so that the progressive changes in structure could be examined. The first change to take place was the removal of carbon, and this was followed by a gradual change in the sulphide layer. After 20 hr. traces of iron oxide appeared in the layer itself as a eutectic structure with the iron sulphide. The amount of eutectic increased progressively on increasing the time of treatment, and the structures after 50 and 100 hr. are shown in Figs. 16 and 17. After 200 hr. there was no sulphide present, but only iron oxide, as shown in Fig. 18. It must be pointed out, however, that the amount of iron as oxide was very much less than was originally present as iron sulphide. The interesting feature of these experiments was that, apart from areas that were originally iron sulphide, there was no iron oxide in the metal.

It was evident that oxygen diffusing inwards from the surface had reacted with the iron sulphide to form oxide. There must in addition have been a gradual solution of sulphur, and probably a counter-diffusion to the surface of the specimen, this diffusion being assisted or promoted by an oxygen concentration gradient in the metal. It would follow from this that the solubility of sulphur in iron increases with the oxygen content (*i.e.*, oxygen in solid solution). This deduction finds confirmation in recent experiments on the overheating and burning of steel, in which it has been found that sulphur migrates to the boundary of the crystal when steels are heated to the burning range.

IV—Consideration of Results

Results obtained in the present investigation have shown that sulphide penetration into steel under carburizing conditions involves first the formation of a molten sulphide on the surface which enters the metal as such by virtue of the fact that it dissolves iron on one side and rejects it on the other. The rate of penetration is thus governed by the diffusion of iron through the molten sulphide, and this is in turn controlled by the difference in carbon content on either side of the sulphide.

The fact that the penetrating layer must be molten fixes the lowest temperature for penetration at the melting point of the iron/iron-sulphide eutectic, *i.e.*, 985° C.

The following two observations support the claim that the penetrating sulphide can carry oxygen in solution:

(*a*) When the sulphide band was formed in the presence of oxygen the lowest temperature for penetration dropped to 960° C.

(*b*) With high-silicon steels the sulphide band was associated with internal oxidation.

The general effect of carbon, manganese, and silicon in the iron is to decrease the rate of penetration. These elements increase the degree of dispersion of the sulphide band, and when this reaches a stage where the latter no longer presents a barrier to the carbon, penetration of the sulphide ceases.

The conversion of the deep-seated layer of iron sulphide to oxide by simply maintaining a suitable oxygen pressure at the surface of the specimen is interesting, especially as this can occur at oxygen pressures too low to oxidize the iron. Similar processes may operate in the embrittlement of steel on heating in atmospheres of low oxygen pressure, as it is possible that other compounds existing at the boundaries may be oxidized in a similar manner.

The results also show interesting related effects between the three elements carbon, sulphur, and oxygen which may be of significance in the segregation or homogenization of steel. The rapid diffusion of sulphur to regions high in oxygen which has been indicated in this work may offer some guidance in solving the problems concerned with the overheating of steel.

This work has now been extended to include non-ferrous metals and penetrating compounds other than sulphides, and results obtained will be published later.

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Historical Note No. 4

The First Stamp Mills in English Industry*

By Dr. H. R. Schubert†

Stamp mills for the crushing of ore were invented by some unknown person about 1500.[1] They were known in Italy early in the sixteenth century and were used for grinding quicksilver ore before it was washed, and also for crushing gunpowder. Vannoccio Biringuccio, in his "Pirotechnia," first published in 1540, described them as being driven by a water-wheel "that lifts with its shaft many heavy and strong stamps of dry holm oak, which fall and strike in various mortars of wood cut out in a beam of oak."[2]

In Germany, stamp mills were known at the same time. A stamp mill for crushing tin ore was erected in Saxony as early as 1505–1507.[3] Agricola, in chapter VIII of his famous "De re metallica," published in 1556, supplied a detailed description of such mills and included several illustrations,

* Received 8th August, 1947.

† University of Reading.

[1] A. Wolf, "A History of Science, Technology and Philosophy in the 16th and 17th Centuries," p. 494. London, 1935.

[2] C. St. Smith and M. T. Gnudi, "The Pirotechnia of Vannoccio Birunguccio," pp. 83 and 414. New York, 1942.

[3] L. Beck, "Geschichte des Eisens," vol. II, p. 87. Brunswick, 1893.

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A—Mortar. B—Upright Posts. C—Cross-Beams. D—Stamps. E—Their Heads. F—Axle. G—Tooth of Stamp. H—Teeth of Axle.

Sixteenth-Century Stamp Mill

one of which is reproduced above. The stamps were of hard wood and were furnished with heads of iron to give them additional strength.[4]

The first application of the stamp mill in England was made in the lead-mining industry in Derbyshire, where it was introduced in 1552 by a German called Burkhard Cranich. In English documents Burkhard Cranich is usually referred to as Burchard Cranyce, or simply Burcot. His place of birth is not given, but it is mentioned that he was from High Germany, which indicates South German origin.[5]

In 1552 Burkhard Cranich erected a furnace mill for smelting lead ore near Duffield, in Derbyshire. According to a description made in 1582 by one William Pendleton, who had been Burkhard's clerk, this mill had also "4 stampers with iron and 2 great irons in the bottom," *i.e.*, it had four stamps furnished with iron heads and probably two large plates of iron on which the ore was placed for crushing. The water-wheel was more than 15 ft. high. By means of this new method the ore was crushed "small like meal and dust."[6] From Duffield the method soon spread over Derbyshire, and it was used in the lead mill erected at Beauchief Abbey about 1570, and also in a lead mill belonging to the Earl of Shrewsbury, built at Chatsworth Park about 1571.[7]

In 1554 Burkhard Cranich left Derbyshire for Cornwall, where he built a smelting house with a stamp mill, thus introducing the method into tin-mining. His lead mill near Duffield was left to his former factor, Nicholas Hall.[8] In 1569 the stamp mill was introduced into the English copper industry by the erection of a mill at the copper mines at Newlands, which belonged to the Company of the Mines Royal's copper works at Keswick, in Cumberland. At Newlands there was a "stamping house" with 16 stamps, and according to an inventory of the works 11 of these stamps were still in working order in 1588, four of them being "beshod with iron," *i.e.*, having iron heads. The stamps were operated by a water-wheel 16 ft. high.[9] The Company of the Mines Royal employed German workers, who brought their tools and engines with them.

In the iron industry stamp mills were not used for ore-crushing, as there was no need to crush iron ore to pulverization point as was done with the other ores mentioned, but stamp mills were used for crushing cinders from the forges, for addition to the ore in the smelting process. This was done in 1704 by Major John Hanbury, who owned furnaces and forges at Pontypool in Monmouthshire and at Llanelly in Brecknockshire. In his "Observations on the Making of Iron," a manuscript valuable for the history of iron-smelting in many respects, Major Hanbury refers to a considerable increase in yield caused by the addition of stamped cinders.[10]

It is little wonder that stamp mills were first introduced into this country by Germans, as their skill in mining was very much appreciated in sixteenth-century England. Their repute in this respect is reflected in Fuller's well known book on the worthies of England, in which the Germans are referred to as "good frogs by sea, but better moles by land."[11]

[4] Georgius Agricola, "De re metallica" (p. 279 *et seq.* of the English translation by H. C. and L. H. Hoover. London, 1942).

[5] Calendar of the Patent Rolls, Philip and Mary, vol. I, p. 159. London, 1937.

[6] British Museum, Add. MS. 6685, p. 118. Public Record Office, Exchequer Depositions by Commission, 24 Elizabeth, Hilary No. 4, and Easter No. 16.

[7] British Museum, Lansdowne MS. 18, No. 49. Public Record Office, Exchequer Depositions by Commission, 24 Elizabeth, Easter No. 16.

[8] Public Record Office, Exchequer Depositions by Commission, 24 Elizabeth, Hilary No. 4. "Acts of the Privy Council" (new series), vol. V., p. 211. London, 1892. *See also* Rhys Jenkins, *Transactions of the Newcomen Society*, 1928, vol. 7, p. 4, and 1939, vol. 18, p. 230.

[9] British Museum, Sloane MS. 2487, folios 9–10. *See also* H. Hamilton, "The English Brass and Copper Industries to 1800," p. 20. London, 1926.

[10] The manuscript is in the possession of Mr. Gordon Booker, of the Clarence Hotel, Pontypool, who kindly facilitated the study of it.

[11] T. Fuller, "The History of the Worthies of England," p. 215. London, 1662.

Measurement of Young's Modulus at High Temperatures*

By M. H. Roberts, B.Sc.† and J. Nortcliffe, B.Sc.†

SYNOPSIS

Measurements have been made of Young's modulus of various steels from room temperature up to 1000° C. The method used was to cause a cylindrical rod of the steel to vibrate transversely with its fundamental frequency. From the frequency and the mass and dimensions of the bar, Young's modulus may be calculated.

The results show a decrease in Young's modulus with temperature, the value at 600° C. being of the order of three-quarters of that at room temperature.

Introduction

THE value of Young's modulus was required for a number of steels (*see* Table I) at elevated temperatures, in some cases up to 1000° C. In the measurement of the modulus by the usual static method, considerable precautions must be taken if results of high accuracy are required. Where measurements have to be taken at high temperatures, the difficulties are considerably aggravated, since only small stresses may be used if creep in the specimen is to be avoided. It was, therefore, considered preferable to use a vibration method, which would avoid these difficulties, since the displacements may be relatively small.

The method adopted was based upon that of Förster and Köster‡ which essentially consists of setting up transverse vibrations in a cylindrical rod and measuring the resonant frequency (*see* Fig. 1). The characteristic frequency depends upon the dimensions of the rod and upon the density and Young's modulus of the material.

Experimental

Measurement of Young's Modulus

The best conditions for the measurement of Young's modulus were first investigated with the specimen at room temperature.

The energy was supplied by a small 4-in. dia. loudspeaker driven by a beat-frequency oscillator. An ordinary piezo-electric crystal gramophone pickup was used as the detector of vibrations, connected *via* the amplifier to the *Y* plates of a cathode-ray oscillograph. The test bar (6 in. long × $\frac{3}{16}$ in. in dia. approximately) was suspended horizontally by two thin asbestos strings attached respectively to a small hook glued to the diaphragm of the speaker, and to the needle of the pickup. To find the natural frequency of the bar, the oscillator was tuned until a large maximum deflection appeared on the C.R.O. When this occurred, the position of the nodes was determined by resting a thin steel needle lightly at various points on the bar, with the oscillator still driving the speaker. The deflection on the C.R.O. varied from zero to the maximum according to whether the needle was placed at the antinodes or the nodes. With the bar resonating with its fundamental frequency there were two nodes, situated at a distance of about one quarter of the length of the bar from the ends. On obtaining the required mode of vibration, the frequency was determined by means of a calibrated frequency bridge placed in parallel with the speaker. This gave more accurate measurement of the frequency than that obtained directly from the beat-frequency oscillator.

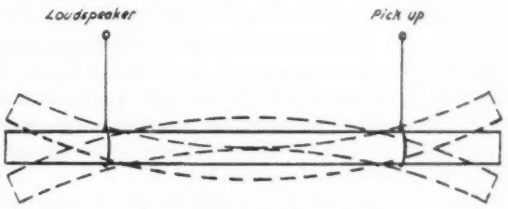


FIG. 1—Mode of vibration

Young's modulus was then given by the formula

$$E = 1{\cdot}041 \cdot \left(\frac{l}{d}\right)^4 \cdot \frac{m}{l} \cdot f^2 \times 10^{-6} \text{ tons/sq. in.} \quad \ldots\ldots(1)$$

where l = length of bar in cm.
d = diameter of bar in cm.
f = natural frequency of bar in cycles/sec.
m = weight of bar in g.

The particular bridge used gave the most accurate measurements of frequency over the range from 400 to 1000 cycles/sec., so the bar diameter was fixed to give vibration frequencies within this range. The length of the bar is limited by the necessity of obtaining a reasonably uniform temperature along it within a furnace of reasonable size. On the other hand, it was found that the longer and thinner the bar, the easier it was to set it in vibration. A bar 6 in. long × $\frac{3}{16}$ in. in dia. was found to be a suitable compromise.

* Received 12th June, 1947.

† Physics Department, Brown-Firth Research Laboratories.

‡ Förster and Köster, *Engineer*, 1938, vol. 166, p. 626.

The supports for the speaker and pickup must be entirely independent, or transmission of vibration through connecting ties will result. Furthermore, both supports must be protected from external vibrations of any kind, by mounting on thick rubber or felt. The very-low-frequency vibrations of the bench or floor may be minimized by connecting a small condenser (about 400 $\mu\mu$F.) in series with the output leads of the pickup. The apparatus is shown in Fig. 2.

It should be noted that it is the adiabatic

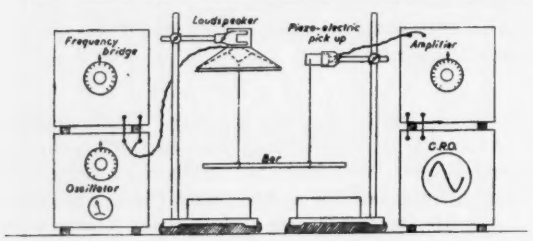


FIG. 2—General arrangement with bar at room temperature

Young's modulus which is measured, but the difference between the adiabatic and isothermal moduli is less than 0·5% and so may be neglected.

Measurement of Young's Modulus at High Temperatures

The only difference between determinations made at high temperatures and those made at room temperature is that the bar must be suspended inside a furnace with a uniform temperature distribution. The arrangement finally adopted was that shown in Fig. 3.

The assembly of the bar inside the furnace had

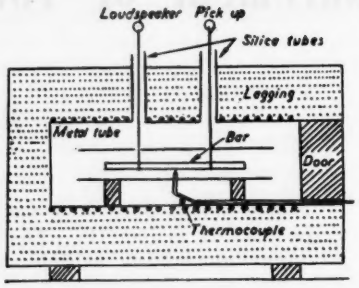


FIG. 3—Furnace assembly

to be carried out whilst the furnace was cold, as the two asbestos strings had to be threaded through the two holes at the top of the muffle case. This was greatly simplified by using a piece of wire with a hook on the end. The bar was supported horizontally, as before, care being taken to ensure that it was well clear of the heat-resisting steel tube which served to equalize the temperature distribution along the rod.

With austenitic steels where there were no transformations in the temperature range over which measurements were made, early experiments showed that the decrease in Young's modulus with temperature was approximately linear, and it was considered sufficient to measure Young's modulus at temperature intervals of approximately 200° C. The form of the curve permitted sufficiently accurate interpolation at intermediate temperatures. With the ferritic steels, however, measurements at smaller temperature intervals were necessary in the neighbourhood of the transformation.

When the temperature at which the first determination was to be made was reached, *i.e.*,

TABLE I—*Compositions of Steels*

Steel No.	Type	C, %	Si, %	Mn, %	Ni, %	Cr, %	W, %	Mo, %	Ti, %	Co, %	Cu, %	Cb, %
1	Mild steel	0·09	0·21	0·22	0·09	0·06	...	...	...	...	...	...
2	0·3% C	0·31	0·30	0·66	0·11	0·07	...	...	...	...	...	...
3	S.L.V.	0·43	3·4	0·48	0·29	7·7	...	...	...	...	...	...
4	F.G.	0·32	0·21	0·21	0·81	12·2	...	...	...	...	...	...
5	Pyrista	0·09	0·86	0·40	1·97	29·3	...	...	...	...	...	...
6	2¼% Ni–Cr–Mo	0·26	0·17	0·49	2·27	0·39	...	0·4	...	...	...	...
7	I.4 W	0·32	1·35	0·52	7·97	20·3	3·85	...	...	...	...	...
8	F.D.P.	0·15	0·87	0·43	8·3	18·6	0·21	...	1·1	...	...	...
9*	F.C.B.	0·15	0·5	0·7	10·0	18·0	...	...	...	...	...	1
10	H.R.C.M.	0·21	1·65	0·56	11·8	23·0	3·1	...	...	...	...	...
11	F.V.S.	0·41	1·43	0·71	14·4	14·4	2·5	...	...	...	...	...
12*	R.326F	0·4	...	4·0	18·0	14·0	...	4	...	7	...	4
13*	R.337A	0·2	0·5	0·7	18·0	14·0	...	4	0·7	7	3·5	...
14*	R.78	0·1	0·5	0·7	18·0	14·0	...	4	0·7	...	3·5	...
15	I.5	0·12	1·43	0·79	21·2	24·3	...	...	...	...	...	...
16	I.6	0·40	2·35	1·32	27·7	15·4	4·5	...	...	...	...	...
17	Vickro	0·10	0·98	1·0	58·6	14·2	0·46	...	...	...	...	...
18	Vickro *A*	0·16	0·76	1·22	62·1	13·9	...	...	...	...	...	...

* Specification Analysis.

TABLE II—*Pre-Treatments and Values of Young's Modulus*

Steel No.	Type	Pre-Treatment (Temperatures in ° C.)	Young's Modulus, tons/sq. in. × 10^3							
			20° C.	200° C.	400° C.	600° C.	750° C.	800° C.	950° C.	1000° C.
1	Mild steel	N.930	13·5	12·7	11·8	10·4	...	...	...	...
2	0·3% C	N.860	13·9	13·2	12·2	10·8	...	...	...	...
3	S.L.V.	O.H.990, T.750	13·7	13·1	12·0	10·6	...	7·8	6·6	...
4	F.G.	O.H.990, T.750	14·2	13·4	12·3	10·8	9·0	...	...	...
5	Pyrista	W.Q.620	12·2	11·5	10·3	8·4	...	6·9	...	5·6
6	2¼% Ni–Cr–Mo	A.C.650	13·2	12·5	11·5	10·3	...	...	...	...
7	I.4 W	A.C.1050	13·2	12·2	11·0	9·9	...	8·8	...	7·4
8	F.D.P.	A.C.1050	12·7	11·7	10·5	9·4	...	8·2	...	...
9	F.C.B.	...	13·1	12·1	10·9	9·7	...	8·6	...	...
10	H.R.C.M.	A.C.1050	12·8	11·9	10·8	9·8	...	8·9	...	7·6
11	F.V.S.	A.C.950	13·1	12·1	11·0	10·0	...	8·9	...	...
12	R.326F	...	13·3	12·5	11·6	10·5	...	9·4	...	...
13	R.337A	...	12·6	11·8	10·8	9·8	...	8·8	...	...
14	R.78	...	12·3	11·5	10·5	9·5	...	8·5	...	...
15	I.5	A.C.1050	12·7	11·7	10·7	9·7	...	8·7	...	7·6
16	I.6	A.C.1050	12·9	12·1	11·3	10·3	...	9·4	...	8·2
17	Vickro	A.C.1050	12·7	12·1	11·4	10·6	...	9·6	...	8·1
18	Vickro *A*	A.C.1050	13·2	12·5	11·7	10·8	...	9·9	...	8·6

200° C., the Sunvic energy regulator which was connected in series with the furnace was set to give the corresponding temperature. When the temperature indicated by the thermocouple had been constant for at least 10 min., a measurement of the natural frequency of the bar was made exactly as before. The mode of vibration, however, could not be checked; but if the gradually changing frequency was "followed up" as the furnace slowly heated up from room temperature, there was no ambiguity regarding the mode of vibration. Observations were then carried out at 400, 600° C., etc., using the same procedure, and hence Young's modulus at the various temperatures was calculated by means of the formula. The results are given in Table II.

To prevent excessive scaling of steels 1, 2, and 6, the bars were plated with a thickness of about 0·001 in. of nickel. The remainder of the steels had sufficiently good heat-resisting properties to make protection of the surface unnecessary.

Precautions

It is obvious from the formula that any alteration in dimensions of the bar during the experiment will affect the result, so that an allowance for expansion at high temperature must be made. If the length of the bar is measured at room temperature and observations are made at a temperature T° C., the formula for the calculation of E must be modified by replacing $\frac{m}{l}$ in equation (1) by the expression:

$$\frac{m}{l\,[1+\alpha(T-t)]}$$

where α = coefficient of expansion of steel,
t = room temperature in ° C.

This correction is of the order of 1½% at 800° C. and is dependent on steel composition.

Another important fact is that any addition to the inertia of the bar lowers the frequency. For this reason, the thermocouple must not touch the bar and the bar must be supported near the nodes, which for the size of test-piece used, are situated approximately 37 mm. from each end. Also, much sharper tuning is obtained when the supports are near the nodes, and hence a more accurate measurement of frequency is possible. On the other hand, the amplitude of the deflections on the C.R.O. falls off considerably the nearer the point of suspension is to the nodes. Supporting the bar at 4 cm. from the ends appears to be a reasonable compromise. Various means of support for the bar have been tried. Wire supports have been found unsuitable owing to their own characteristic vibrations. Thin cotton supports were found to be best, but as their use is limited to room temperature, thin asbestos

TABLE III—*Young's Modulus as Determined by the Usual Static Method*

Steel No.	Type	Young's Modulus, tons/sq. in. × 10^3			
		20° C.	200° C.	400° C.	600° C.
1	Mild steel	13·3	12·6	11·2	...
8	F.D.P.	12·5	11·6	10·5	9·3
9	F.C.B.	13·2	...	...	...
12	R.326F	13·2	...	...	...
13	R.337A	13·0	...	...	...
14	R.78	12·8	12·0	11·0	9·6

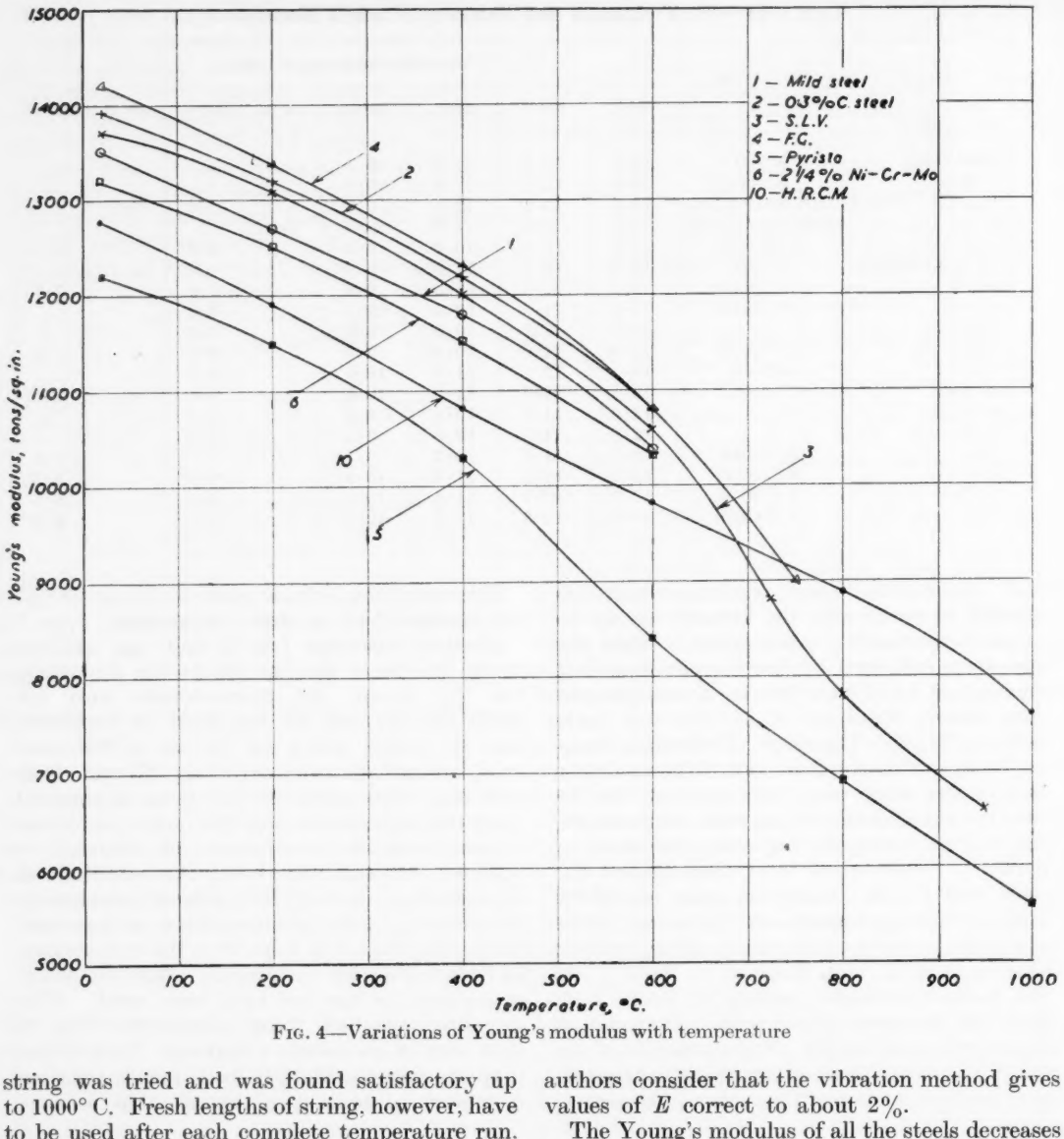


FIG. 4—Variations of Young's modulus with temperature

string was tried and was found satisfactory up to 1000° C. Fresh lengths of string, however, have to be used after each complete temperature run, as the string becomes very crumbly and easily broken.

Results

Curves showing the variation of Young's modulus with temperature have been plotted in Fig. 4 for steels 1–6 and 10; with the remaining steels the variation with temperature is practically linear, so that interpolation is simple.

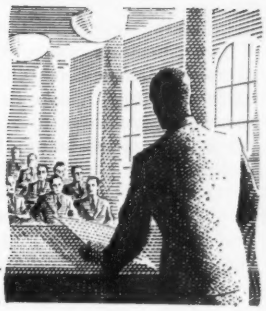
The agreement between the results given by the vibration and static methods (*see* Table III) is satisfactory on the whole, the difference in the case of R.78 (steel 14) possibly being due to a cast-to-cast variation. In general, the authors consider that the vibration method gives values of E correct to about 2%.

The Young's modulus of all the steels decreases by about 25% between room temperature and 600° C., the decrease being almost linear up to the latter temperature. The modulus for austenitic steels continues to decrease linearly up to 800° C., but with the ferritic steels 3, 4, and 5, there is a considerable increase in the rate of fall of Young's modulus above 600° C.

Acknowledgments

The authors are indebted to Dr. C. Sykes, F.R.S., Director of Research, The Brown-Firth Laboratories, for permission to publish this paper. They would also acknowledge valuable discussions with Mr. L. Rotherham and Dr. F. W. Jones.

DISCUSSION ON PAPERS



DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Discussion on

THE PROTECTION OF IRON AND STEEL AGAINST CORROSION

A meeting to discuss the protection of iron and steel against corrosion was held at the offices of the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday, 26th June, 1947, at 2.30 P.M. Mr. T. M. HERBERT, Deputy Chairman of the Corrosion Committee and Chairman of the Protective Coatings Sub-Committee,* occupied the Chair.

The following papers were presented and jointly discussed: "The Effects of Different Methods of Pretreating Iron and Steel before Painting," by F. Fancutt, F.R.I.C., A.M.I.Chem.E. (*The Iron and Steel Institute*, 1936, *Special Report No. 31.*) "The Protection of Iron and Steel by Metallic Coatings," by J. C. Hudson, D.Sc., and T. A. Banfield, Ph.D., F.R.I.C. (*Journal of the Iron and Steel Institute*, 1946, No. II, pp. 229P–256P.)

The **Chairman**: The object of this meeting is to discuss two papers, one of which will be presented by Mr. F. Fancutt and the other by Dr. J. C. Hudson, which describe two separate phases of the work conducted by the Protective Coatings Sub-Committee of the Corrosion Committee.

We have received a message from Dr. C. H. Desch, F.R.S., the President of the Institute, saying that he would very much have liked to be present and expressing his regret that he is unable to be here.

Mr. **F. Fancutt,** in presenting his paper said:, This paper has been in print for quite a long time, and, having regard to the fact that these researches were started some seven years or more ago, it is necessary to emphasize that the information available regarding the pretreatment of iron and steel previous to painting is much more complete today than it was at the time these tests were concluded.

For many years past there have been efforts on the part of various people and organizations to emphasize the importance of surface preparation of steel structures. Unfortunately we see no direct evidence on a large scale that the lessons of the past have been absorbed and that people have profited by them, but it is interesting to note that when part of this information, in a somewhat different form, was presented before a section of The Institution of Civil Engineers in the early part of this year the reaction was on the whole very encouraging, and, I hope, so far as the users of steel are concerned, a promise of better things in the future.

(Mr. Fancutt, then showed a number of slides, which illustrated, among other things, the superiority of pickled specimens over specimens covered in mill scale, even in the absence of rust, and the effect of incomplete removal of mill scale on the durability of the paint system. They emphasized, he said, the main point of his paper, that to attain maximum protection from paint the surface must be properly prepared.)

In concluding his presentation of the paper Mr. Fancutt said: I think that I have shown sufficient to emphasize the real point behind the paper—a point which, unfortunately is all too easily lost sight of—namely, that the overall performance of any paint system is entirely dependent on the surface preparation which is provided previous to the painting scheme being applied. This is not only on the score of freeing the surface from rust and mill scale, but also of providing the paint with that all-important facility, which is essentially linked up with durability,

* The Corrosion Committee was originally a Joint Committee of the Iron and Steel Institute and the British Iron and Steel Federation, and reported to the Iron and Steel Industrial Research Council, but was transferred to the care of the British Iron and Steel Research Association on 31st December, 1946.

of adhering to the surface which it has to protect.

The time has come when, from a national point of view, we should consider the wastage which occurs each year from corrosion, much of which could be prevented by some attention being paid to surface preparation either before the sections are fabricated or, if this is not possible, after erection. This point is of special importance in these days of paint shortages, in that it does enable even paints of only average performance to give more in the way of durability than might normally be expected from them.

Dr. **J. C. Hudson,** in presenting the paper by himself and Dr. T. A. Banfield, said: In presenting this paper is is unnecessary to go at great length into a discussion of the experimental programme and methods and the results themselves. The main point is, I think, that in these investigations which Dr. Banfield and I have carried out under the direction of the Protective Coatings Sub-Committee an attempt has been made to obtain reliable data on the performance of protective metallic coatings when applied to mild steel, the range of coatings selected being as wide as possible within reasonable limits of industrial practicability.

There can be no doubt of the importance and value of protective metallic coatings for mild steel. This, in fact, has long been generally recognized for the protection of sheets, light-gauge parts, and similar materials. I hope that as a result of the Sub-Committee's investigation the application of these valuable means of protection will be encouraged in many other cases, including heavy structural steelwork, because it is evident that even in the field of heavy structural steelwork, from which metallic coatings—with the possible exception of hot-galvanizing—have hitherto been excluded to a very large extent, substantial advantages are to be gained.

In the case of the Committee's exposure stands for instance, which are virtually structural steelwork on a small scale, it is now our practice to specify that all new stands shall be either hot-galvanized or, alternatively, protected by means of sprayed aluminium. In our own very limited experience that is a much more efficient and economic procedure than the one which we adopted originally of painting over bare steel, either after the application of a shop coat of priming paint or, alternatively, after allowing the steel to weather on the site.

It should be emphasized, however, that for the permanent protection of structural steelwork—with the possible exception of the purest and least corrosive atmospheres—we do not envisage the use of metallic coatings alone. In most cases metallic coatings should be combined with painting and form the basis of a properly thought-out protective scheme embracing both a metallic coating and paint. That aspect of the problem of protecting iron and steel, which so far has received but little attention, is now being studied by Joint Technical Panel J/P1 of the Protective Coatings Sub-Committee with the paint industry, under the chairmanship of Mr. Fancutt, and we hope to commence a series of tests in which this question will be investigated in some detail so as to provide a suitable choice of painting schemes for use over metallic coatings applied to mild steel. We hope to commence those tests in the early part of next year.

As you will see, this paper by Dr. Banfield and myself was written over a year ago, but on rereading it I think that, subject to such constructive criticism as we hope will be offered in the course of discussion, it is a reasonable and fair summary of the experimental facts as they stood at the end of five years' exposure. The only alteration which I should suggest if I were to rewrite this paper in collaboration with my colleague today is perhaps a slight change of emphasis. It is evident that the three most promising metals for the protection of iron and steel, at any rate on the results of our tests, are, in alphabetical order, aluminium, lead, and zinc, and I think that perhaps we have not stated the case for the use of aluminium protective coatings as strongly as I should now do. In other words, for many purposes aluminium can be regarded as a reasonable alternative to zinc, and I should expect that, under some conditions, particularly where exposure to atmospheres of high humidity and sulphur gases was concerned, the aluminium coating would probably prove rather better than zinc. That does not, of course, detract from the fact stated in the paper that zinc is in general a good all-round protective metallic coating for mild steel.

There are two points which I think we might note. The first is that there is no evidence that cadmium coatings are superior to zinc; in fact, so far, the conclusions of Dr. Banfield and myself are entirely the reverse. That should be noted, because the statement is still to be found in text-books that cadmium is preferable to zinc. Secondly, the main general conclusion drawn from these tests is that it is very important to pay attention to the question of coating thickness. I may add that that fact emerges not only as regards metallic coatings, but will also emerge from the work of the Joint Technical Panel J/P1, under Mr. Fancutt's direction on painting schemes.

Figure A brings out this fact a little more clearly than it is brought out in the paper itself. It shows the life to failure at Sheffield of various types of zinc coating as a function of the coating weight. The only difference from the similar graph presented in the paper is that where duplicates of nominally the same coating thickness applied by the same process are concerned the results have been averaged; in other words, there is less detail shown, and the slight deviations due partly to experimental error tend to be smoothed out. It is evident that the method of application, in these tests at least, has not played a major part in determining the coating life.

It has been stated by the British Non-Ferrous Metals Research Association, on the basis of experimental evidence obtained by them, that under certain conditions at least, differences in the behaviour of zinc coatings may occur according to whether or not they consist essentially of metallic paint, as in the case of sprayed or electrodeposited coatings, or contain an iron–zinc alloy layer, as in the case of hot-dipped and sherardized coatings. There is slight

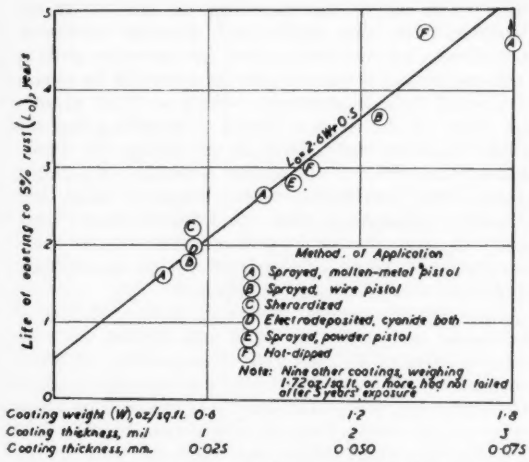

Life of coating to 5% rust (L_0), years
$L_0 = 2.6W + 0.3$
Method of Application
A Sprayed, molten-metal pistol
B Sprayed, wire pistol
C Sherardized
D Electrodeposited, cyanide bath
E Sprayed, powder pistol
F Hot-dipped
Note: Nine other coatings, weighing 1·72 oz/sq ft. or more, had not failed after 5 years' exposure
Coating weight (W), oz/sq ft. 0·6 1·2 1·8
Coating thickness, mil 1 2 3
Coating thickness, mm. 0·025 0·050 0·075

FIG. A—Lives of zinc coatings on mild steel exposed to the Sheffield atmosphere

evidence of this here, but whether or not that is merely " the luck of the draw " is a matter on which at this stage we have an open mind. The main point is that in collaboration with the British Non-Ferrous Metals Research Association the Corrosion Committee, under the immediate guidance of the Protective Coatings Sub-Committee, is starting on a series of tests of zinc coatings in various circumstances which will answer that question.

Dr. **T. A. Banfield,** supplementing what Dr. Hudson had said in presenting their paper, referred to Dr. Hudson's statement that zinc coatings were better than cadmium coatings, and observed that this result had been obtained in an industrial atmosphere. As yet they had no data on non-industrial atmospheres, and he was not sure whether cadmium might not prove better than zinc in a marine atmosphere, for instance.

DISCUSSION

Dr. **U. R. Evans** (Cambridge University) : I should first like to offer my very sincere congratulations, and those of my colleague Dr. Mayne, to all three authors for this valuable collection of accurate observations. We may accept all the experimental results without reservation ; not only are the authors qualified and careful observers, but insofar as their work intersects the lines of the exposure tests organized elsewhere there is reasonable agreement. No serious disaccord exists, for instance, with the tests organized from Cambridge, and any apparent discrepancies could, I think, easily be explained away.

As regards the practical conclusions to be drawn from the figures, I am in agreement with about 99% of them. If I confine myself to the remaining 1%, I would ask you not to forget the other 99% about which we are all in full accord.

The very satisfactory linear curves connecting life and thickness, on which I would congratulate Dr. Hudson and Dr. Banfield, suggest at first sight that a fairly accurate computation of the life of a coat could be obtained by measuring the average thickness. That might not always be the case under conditions of immersed corrosion, at least with zinc coatings, because the electrochemical properties of zinc and zinc–iron alloys are different. It is approximately true, no doubt, for atmospheric corrosion, provided that the thickness of a coating is uniform ; if the coat is not uniform it becomes necessary to consider the chance that a place of abnormally low thickness coincides with a place where the attack is unusually severe. In order to assess the expectation of life we require not just a single figure for the average thickness, but a frequency curve showing the distribution of different thicknesses.

To give a simple example : Let us imagine a roof of slate or glass in an industrial district ; rain is trickling down the roof, picking up acid fumes from, perhaps, a nearby chimney, and running off either on to a lower galvanized roof or, perhaps, on to guttering, at a limited number of points. In such a case it will be found that at these points the attack is unusually severe, because they are receiving more than their proper " ration " of corrosive substances. If the coating is of uniform thickness, the points which receive the same amount of acid will have about the same life. If the thickness is not uniform, then some of them (where the thickness is great), may have a life longer than that which would be calculated from the average thickness, but that will not console the owner for the fact that others will have a life which is abnormally short. Speaking generally, therefore, it may be said that if the thickness of the coating is not uniform, less satisfaction will be obtained than if it is uniform.

Some years before the war there was on sale in this country a consignment of galvanized iron, said to come from the Continent, which had a deplorably short life. That short life was almost certainly due to the lack of uniformity in the thickness of the zinc coat. Had the zinc been uniformly spread out, the life would not have been nearly as short as in point of fact it was found to be.

Again, let us consider wire. If it is uniformly electrodeposited with zinc by, say, the Tainton process, so as to produce the same thickness everywhere, that should give the best " moneys-worth " for the zinc applied. Let us compare the behaviour of wire coated by one of the less satisfactory hot-dipping processes ; I will not say that all hot-dipping processes give non-uniform coats, but in general it is less easy to obtain uniformity than by an electrolytic process. At the thick places the coating will tend to crack when the wire is bent ; where the coating is thin it will corrode through abnormally quickly, so that we shall have the worst of both worlds. It is better to aim at a uniform coating.

Again, consider the case of articles of complicated form which are galvanized after being bent into shape. If the zinc is put on by electro deposition there is a tendency for it to be thinnest in the recesses ; if it is put on by hot-dipping there will frequently be extra zinc at the crevices, which may be better for some

purposes and worse for others. I feel that cases do exist where the coating procedure, as such, may be very important indeed.

One cannot always be indifferent to the process adopted, and clearly it is convenient to have a process which enables the metal to be applied thickly just where thickness is called for. That, I think, is where the spraying processes possess a special advantage. Judgment can be used, and metal can be put on thickly where thickness is needed and thinly where it is not needed.

I do not feel that it is a valid argument against aluminium that only one satisfactory process exists for its application; after all, there is need for only one process for putting-on a metal, and the process available is a good process. I was glad to hear Dr. Hudson recommend sprayed aluminium in his remarks in presenting the paper. In some of the tests organized from Cambridge and carried out by Mr. Britton before the war it was found that specimens sprayed with aluminium from the wire pistol, and carrying outside the aluminium coating one coat of cheap iron oxide paint were, after seven years in London, almost unchanged, apart from the soot. It was found that in relatively soot-free places the paint applied on aluminium kept its colour very much better than the paint applied directly on iron. The view that aluminium spraying followed by painting is a reliable method of protecting steel was certainly borne out by experience during the war, when the method was used on the hydrogen cylinders employed for balloon barrages in different parts of the world; the conditions were often drastic, but the protection was good.

There is one situation, however, where I feel a little doubtful about aluminium spraying, namely, where there is much vibration or where slender strips of steel are subjected to continuous whipping. Personally, I do not know very much about the corrosion-fatigue properties of aluminium-sprayed steel, and I think that, unless data exist on that subject, one should go a little cautiously in recommending aluminium spraying in such a situation.

To pass to Mr. Fancutt's admirable paper, here also I should like to express very general agreement. We have organized some tests from Cambridge on pretreatments before painting; these have included specimens for which important precautions had been (if I may put it so) "intentionally neglected." For instance, in some cases, after pickling we were "very careful to forget" to wash the specimens. Comparison with properly treated specimens showed that a good deal of latitude could be allowed in pretreatment methods without very serious results—always provided that the scale and the rust were somehow got off; if they were left in position, then even good painting systems gave relatively poor results. That, of course, is in accord with Mr. Fancutt's results.

I think that we do possess a means of getting good performance from paint applied to *engineering steelwork*, because descaling and derusting, applied on a *large scale*, whether by pickling or by shot-blasting, are not very expensive operations. However, cases exist where this provides no answer at all. Consider what one might call *domestic steelwork*. A residence has been converted into a series of flats, each one provided with its private approach by means of a steel outside staircase. Suppose that after a few years all the paint is found to be lifting and the whole structure rusty. It is no use telling the owner that he must erect in the garden a number of pickling tanks, some containing warm sulphuric acid and others hot phosphoric acid. A different answer altogether is here necessary, and other situations could be mentioned where a paint that can be successfully applied to *uncleaned* steel is required.

There are two general cases: First, the painting of steelwork carrying mill scale and broken up with patches of rust, and secondly the painting of steelwork which has rusted all over, having lost its scale. At Cambridge, where Dr. Mayne is working on these subjects, we are inclined to think that for the first case the zinc-rich paints may come to provide the solution, although we cannot at the moment be certain of this. The zinc-rich paint after drying is an electrical conductor; the zinc particles are in electrical contact with one another, so that if they make contact with the steel at the places still covered with mill scale one gets cathodic protection at the rusty patches. The conductivity of the paint is all-important, and Dr. Mayne has apparatus for measuring this.

For the second case, where there is rust all over the steel, we think it possible that the metallic lead paints will provide the answer. From Dr. Mayne's work it is fairly certain that here the true protection comes through the formation of lead soaps. There are other lead pigments which provide a supply of lead soaps, and indeed some give too much. The old-fashioned type of red lead, which contains litharge, develops plenty of lead soap, but if not freshly mixed it is liable to set hard in the pot. Some of the metallic lead paints seem to furnish a supply of lead soaps at the rate required, but at the same time they will keep fairly well in the pot.

Those two classes of paints are not actually mentioned in Mr. Fancutt's present paper, but possibly they will be dealt with in a further instalment, which will be greatly welcomed.

Mr. **F. G. Dunkley** (London, Midland and Scottish Railway Company, Derby): I have had the privilege of being associated with the work on which the paper was based, and I feel that there is a real need for a better appreciation by both paint and steel users of the need for preparing their surfaces before painting. So far, there has been little response on the part of those who could take the initiative in the introduction of pickling or other means of preparing steel; there has been a reluctance to introduce the necessary equipment, and until this is overcome the behaviour of paint will continue at a level much below that of which it is intrinsically capable.

To be able to follow an investigation such as this, stage by stage, and to see the excellent performance of quite average paints when applied to descaled rust-free surfaces, as compared with rusty and scale-bearing surfaces, is an experience which can bring

conviction in a way which perhaps the reading of a paper cannot achieve. I do hope, however, that the outcome of this meeting will be a greater appreciation of the need for adequate pretreatment of steel for all painting purposes.

There is one aspect of this matter which should, I feel, receive greater emphasis than is given in the paper, namely that the value of correctly prepared surfaces is not spent at the end of the first "paint life," but will remain throughout the life of the structure—so long as a reasonable standard of maintenance is observed. This follows as the result of the increased adhesion, which helps to prevent the spread of corrosion from a damaged area, and the absence of scale, the presence of which remains a potential source of fracture of the protective coating. The increase in the paint life in the second and subsequent generation will not be so spectacular as in the first, but will nevertheless be quite substantial.

Mr. **E. Bateson** (Messrs. Rendel, Palmer and Tritton, London): When I was invited to attend this meeting I was also asked to take part in the discussion, but I did not submit my name, as I felt that there would probably be many speakers who could deal with the subject far better than I. I cannot resist the temptation, however, to follow the last speaker. I am neither a metallurgist nor a chemist, although I know something of each subject, but I do claim to be a practical structural and bridge engineer. I have spent my life principally in that work, and I can assure the last speaker that one of our biggest bugbears is the efficient cleaning of steel. I am firmly convinced that, unless the steel is really thoroughly cleaned, any form of after-treatment is a pure waste of time. If you clean the steel efficiently, really removing the rust and especially the mill scale—which is almost impossible by normal cleaning methods—I think you could apply the cheapest paints and still obtain reasonably good results. On the other hand, if the steel is not properly cleaned, not even the most highly developed and expensive chemical composition will save you.

In 1938 my firm proposed to carry out what would have been the largest steelwork-protection experiment the world has ever known. This was in connection with the New Howrah bridge, two papers on which were recently read before The Institution of Civil Engineers. It is a cantilever bridge with a span of 1500 ft., and the superstructure contains 25,000 tons of steelwork, much of it mild steel. In the parts where economy could be effected by reducing the deadweight, high-tensile steel of several types was used.

Considerable thought was devoted to the question of cleaning, as large-scale organization would obviously be necessary to deal with members up to 45 ft. or so in length, 7 or 8 ft. in depth, and weighing up to 70 tons. This was a very great departure from ordinary metal-spraying-shop practice, where the work is usually easily turned over by hand. Unfortunately, the war came along and the ambitious metal-spraying scheme had to be dropped.

Even then we still hoped to clean the steel properly by shot- or sand-blasting, but as the equipment could not be obtained that also had to be abandoned, and we were compelled to fall back on the time-honoured but disgraceful methods of hand-scraping, scratching with wire brushes, etc. However, the conscientious efforts of the contractor, aided by careful supervision, produced a satisfactory job. The painting was finished about the end of 1942 and has hardly been exposed long enough to provide much useful information, but a certain amount of patch-painting has been necessary. The priming paint was red lead, followed by two coats of aluminium paint, the first of which was brush-applied and the second one sprayed. It was found that the second coat of aluminium paint could not be satisfactorily brushed, as the undercoat "picked-up."

There are really three papers before us, namely, the paper by Mr. Fancutt and Dr. Hudson, read before The Institution of Civil Engineers, the paper by Dr. Hudson and Dr. Banfield on the protection of iron and steel by metallic coatings, and the paper by Mr. Fancutt on methods of pretreating iron and steel before painting. These papers provide a tremendous amount of food for thought, and I confess to some mental indigestion, but I should like to summarize my own reactions to the papers.

First and foremost, you must clean the steel properly, or subsequent treatment is a waste of time. Secondly, for normal purposes you can obtain adequate protection by the use of zinc (I exclude particular atmospheres, such as smoky and industrial atmospheres, atmospheres charged with acid fumes, and so on). Thirdly, the protection afforded by zinc being by a sacrificial action, the amount of protection afforded is directly proportional to the amount of zinc deposited and—though I know that at least one member of the audience does not agree with me on this point—is irrespective of the method by which it is deposited.

I am very interested to hear views on the use of aluminium coatings, because it is necessary to find a substitute where zinc is unsatisfactory, and, if I understand correctly, aluminium apparently provides a satisfactory substitute. In the case of aluminium, it seems to me that the protection is provided by the hard skin of surface oxide which forms on the aluminium and not directly by the aluminium itself. I would suggest—speaking subject to correction from metallurgists and other specialists who are qualified to express an opinion—that that is why the aluminium-powder process fails, because the particles of aluminium are already coated with that film of oxide on which protection eventually depends. That theory would appear to account for the reported failure of the aluminium-powder process to produce a satisfactory aluminium coating. In other words, it appears to be a physical disability.

Dr. **W. D. Jones** (Schori Metallising Process, Ltd., London): With regard to the paper by Dr. Hudson and Dr. Banfield, I am impressed by the tremendous amount of work involved in this investigation, and I am wondering whether it has been adequately appreciated. I must also congratulate the authors on the great amount of care and detailed attention which

they have given to the matter. Their remark that more than 10,000 thickness tests were made in the course of the survey affords only a minor clue to what must have been involved. By the publication of this paper the authors have rendered a very remarkable service to industry, and it is to be hoped that the paper will receive general publicity, so that industry in general will have a chance of appreciating it and making use of it. My own Company, being engaged in the business of the protection of steel from corrosion, have frequently in the past felt the need for more accurate data which could be passed on to companies and undertakings concerned in the erection and maintenance of steelwork, and I should like to say that we particularly appreciate the value of this work and intend to make use of it in the future.

Having said so much, perhaps I may be a little unkind and remark that, in spite of the amount of work which has been involved, the paper does not go far enough. I am sure that the authors would be the first to agree with me. In taking a decision concerning the best methods of protecting industrial steelwork from corrosion, it is necessary not only to be able to assess the technical value of various processes but also to know something about costs. I think that perhaps the authors might have increased the value of their paper had they added an appendix which went into the economics of protective processes, at least to a certain extent. Although personally I have few doubts about this subject, I feel that many people in industry would like to have an authoritative statement on the relative value and cost of, for example, paint on steel, zinc coating on steel, and paint on top of zinc on steel, considered from the point of view of initial cost and maintenance costs over a period of years.

It is the practical experience of my Company—and I am inclined to think that the work described in this paper substantiates it—that the most satisfactory method of protecting steelwork from corrosion, taking into account the question of cost, is to coat it first of all with metallic zinc by one method or another, followed by a suitable paint. While a zinc coating in itself is undoubtedly better than a paint coating on steel, nevertheless zinc followed by paint is substantially better still, and is much the best proposition.

Perhaps the authors could best render a service to the industry if they would compile an authoritative statement in the form of a short paper based on their work in this investigation, together with data from reliable investigations made elsewhere, in other words a statement containing general recommendations to industry for the protection of steel from corrosion, written in a style which will enable it to be appreciated easily by the people to whom it is directed.

If my Company were asked to advise industry on this problem our recommendations would probably be on the following lines, and I should be very glad if the authors would state whether in general they agree with these conclusions, because my Company attach a great deal of importance to the opinions of Dr. Hudson and Dr. Banfield, and their agreement or otherwise might very well influence the policy of the Company.

First, from a long-term point of view, the best and possibly the cheapest method of protecting steel from corrosion, in our view, is to coat it first with zinc, followed by a carefully chosen paint or plastic film.

Secondly, there is the question of whether as a metallic undercoat in this country, in an industrial atmosphere, zinc is to be preferred to aluminium or not, looking at it from the point of view of its sacrificial action. I am not clear from the paper whether the authors have made up their minds on that point or not, although I think it is clear that a great deal of consideration should be given to lead in certain types of atmosphere.

Thirdly, I think that there is very little doubt that the benefit of the zinc coat depends almost entirely on the weight of zinc applied per square foot and not on the method of application, though the authors might agree that some processes are more expensive than others.

So much for generalizations. With regard to the paper, I should like to make the following miscellaneous points. I have become convinced that it would be desirable if the manufacturers of protective coatings described their coatings in terms of ounces per square foot rather than in terms of thickness, as generally seems to be the case. In making that statement I appreciate that my own Company has in this respect been as guilty as anyone in the past.

A second conclusion to which I have come in studying the paper is that if you must use aluminium for the protection of steel you should not put 3% of copper in it. In point of fact the Schori coatings examined by the authors contained not only 3·3% of copper and 0·4% of iron, but more than 1% of other metallic impurities. I realize that when this work was commenced some years ago possibly only secondary aluminium powder was available, but I must confess that I am at a loss to know why the authors have allowed that to happen.

Dr. **J. C. Hudson**: Your Company put it in themselves.

Dr. **W. D. Jones**: I know, but were you aware of it at the time?

Dr. **J. C. Hudson**: No. but your Company should have been, surely.

Dr. **W. D. Jones**: That is a point of which we are only too conscious, but, that being so, I am a little hurt that the authors went on to make a direct comparison with coatings prepared from pure aluminium. It is not merely a question, as the authors remark, that the presence of copper is likely adversely to affect corrosion resistance; it is in fact *very well known* that aluminium–copper alloys are substantially inferior. The alloy which was used appears, as far as we can tell from the analysis, to be a secondary aluminium alloy, and it is generally appreciated that that alloy is inferior to pure aluminium even when in the right condition of heat-treatment, which this was not; otherwise, what would be the point of Alclad? However, mistakes occur in the best-regulated companies, and as far as a direct comparison of aluminium coatings obtained by the Schori process with those obtained by other processes in which pure

aluminium is used is concerned, I need only quote the remarks of Rollason on the work of Semple.

I appreciate that the authors have made a disclaimer concerning the influence of copper on the results, but I feel that perhaps some of their statements are hardly just. For example, on page 247 of their paper they reach the conclusion that the powder pistol cannot be recommended for aluminium coating. When this paper is printed in its final form, I suggest that the authors should make a more accurate statement of their conclusion, which I think should be that an aluminium–copper alloy sprayed by the powder pistol is not suitable for the protection of steel. However, that is a minor matter and must not be allowed to detract from the immense value of the work as a whole.

Mr. **F. A. Rivett** (Schori Metallising Process, Ltd., London): My colleague Dr. Jones has already said all that needs to be said on the question of the aluminium spraying at the time when Dr. Hudson and Dr. Banfield made their tests, but I feel that it may be useful to comment on two commercial examples of the value of zinc spraying which have come to light recently. The first is a result of the war. The steel lifeboats of the liner *Orcades* were zinc-sprayed in 1937 on the Clyde. The liner herself was sunk in 1944 by enemy action off Capetown, and the ship's complement escaped in the lifeboats and were subsequently picked up by small boats which had no accommodation for the lifeboats themselves, so that these were cast adrift. We have recently heard the sequel to this. The lifeboats were drifting for about ten months after the sinking of the liner, and they were collected, some on beaches and some picked up on the high seas, and brought back to England as the property of the Ministry of War Transport. They were examined, and after that very severe trial, afloat in the Atlantic and full of sea-water for that period of time, three of them were passed out for immediate service with other boats, and of the remainder such damage as there was was due to mechanical damage done during the launching of the boats themselves. The Orient Line, from whom we obtained these figures, conclude that steel zinc-sprayed by the Schori process and subsequently painted has been proved in service as a method of preventing marine corrosion.

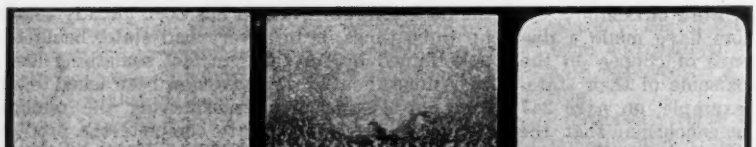
The other interesting point which I want to mention has some connection with Mr. Bateson's statement on the protection of bridge steelwork. We zinc-sprayed approximately half the steelwork of the Menai Straits suspension bridge when it was rebuilt in 1940 by Dorman Long. It was decided to zinc-spray all the high steelwork, which could not be reached for maintenance purposes, and to leave all the deck steelwork, which the engineers felt could easily be maintained. The work was completed in 1940 and has been examined very carefully this year, seven years later. The contrast between the deck steelwork and the high steelwork is most remarkable. We have examined it with consulting engineers and the Ministry of Transport and the surveyor responsible for the maintenance of the bridge. All the high steelwork has the paint coats perfectly intact, but the deck steelwork, which has been already touched-up three times, is in a very bad state, being badly undermined by rust, and in fact something has got to be done about it. We have now been asked to quote for shot-blasting and zinc-spraying the remainder of the steelwork *in situ*, to complete the protection of the bridge.

I felt that these two instances of the greatly increased life of paint on top of sprayed zinc might be worth recording at the time of the discussion of this paper, although it is probable that it will be some years yet before the full value of this method is demonstrated.

Mr. **W. E. Ballard** (Metallisation, Ltd., Dudley): Most of you would expect me to follow the last two speakers, as the sole representative of my firm here today. In the first place, I should like to say that although the paper by Dr. Hudson and Dr. Banfield is excellent, I would suggest it could be given added value by the inclusion of a table showing the comparative virulence of typical atmospheres; such a table is given in the book by Dr. Hudson. The impression may be given to some that metal coatings last only a few years in all conditions of exposure, as it may not be fully realized how severe is the Sheffield test.

With regard to the work mentioned by Mr. Rivett, it is quite recent and I do not think that it has direct reference to the paper, but if examples are to be quoted I would mentioned that in France there are lock gates which were sprayed with zinc 0·004 in. in thickness by the wire process in 1922 and not painted afterwards, and they are still perfectly satisfactory and can be seen at any time.

I felt that it was very likely that the suggestion would be made that the failure of the powder-sprayed aluminium was due to the presence of 3% of copper. I have always held the view—and my Company originally held the patents for the three processes—that coatings produced from powder have different physical properties from those produced by other methods. The powder particles cannot all be melted in the flame of the gun. I think that this is easily proved, because sample steel plates can be sprayed and exposed in any way one likes, and the difference between the aluminium coatings will be seen immediately. An example which can be repeated as many times as you like is shown in Fig. B. The centre specimen is sprayed with the purest aluminium powder which can be obtained. The one on the left is sprayed with powder containing 4% of copper and other impurities. The other specimen is sprayed by the wire process using aluminium of 99·8% purity, and you can see the result of exposure to distilled water. The pure aluminium powder has rusted in two days and the impure in one day, but when the test was finished at the end of 24 days there was no mark on the wire-process specimen. The thicknesses on the three samples were equal and were most carefully checked. There is no doubt that similar results are always obtained. The aluminium particles in the coatings produced by the powder system are covered with oxide and



Grade II powder; rusting occurred in 1 day | Grade I powder; rusting occurred in 2 days | Wire process; no rusting occurred

All samples tested for 24 days

FIG. B—Samples of steel plates sprayed with 0·003 in. thickness of aluminium and tested half-immersed in distilled water

some of them are not melted, this being the main cause of the difference in behaviour, and not the chemical composition of the coating.

A similar effect is observed in preparing micro-samples of aluminium sprayed by the different processes. If the etching is done with dilute caustic soda, as is quite normal, samples produced by the wire or molten-metal process take 2 min. to etch, while similar samples produced by the powder process etch in 4 sec.

I agree most emphatically with Dr. Jones that the coatings should be specified either by thickness, which can be measured, or by weight, but I prefer thickness to weight, because weight is an average value. Dr. Jones and I know that there have been people who state the thickness of deposits as so many coats. This obviously has no meaning; the passage of the pistol quickly over the surface gives one coat, just as does one pass carried out more slowly. It is an American idea, and I heartily agree with Dr. Jones that the sooner we hear the last of it the better.

Our experience of cadmium coatings has been very similar to that of the authors. The only time that we have found cadmium slightly better than zinc has been in stagnant water. In sea-water it is no better than zinc and is very much more costly.

Dr. Jones has asked the authors to be specific in their reply and state their preference, zinc or aluminium. My idea is that for industrial or very humid atmospheres I would prefer aluminium, and I would use this metal in contact with soft waters. In hard or sea-water, under immersed conditions, we would again prefer zinc, which is also be to preferred in pure dry conditions.

Dr. Jones mentioned one point on which he was not quite satisfied with a statement in the paper, and I should like to refer to another unsatisfactory statement, in the description of the processes. There is a note that the powder process seems to be more rapid, and the large figure of 100 sq. ft./hr., or something of that nature, is suggested. If that were true, it would of course mean that the wire process, for which no such claims a re made, would be much more expensive, but in point of fact that is not true; the cost of both processes is very similar.

I do not agree with Dr. Jones' suggestion that the authors should make some reference to costs in a technical paper of this sort, because costs vary from day to day in this ever-changing world, but I think that someone might very well go into that matter in another type of paper, as many misleading statements have been made.

Dr. **S. G. Clarke** (Armament Research Dept., Woolwich): I have read both these papers with very great interest. They contain an enormous amount of work on a subject which is obviously of great industrial importance. I think that perhaps it might be said, so far as the paper by Dr. Hudson and Dr. Banfield is concerned, that the subject is to some extent limited to industrial atmospheres and sea-water immersion, because, as they rightly say, it will probably be many years before their results on the exposure of specimens in other atmospheres are available. The principal interest of the paper, therefore, lies on the industrial-atmosphere side.

There are so many points in the paper that it is difficult to know where to start, and I do not intend to try to cover many of them, but I had an uneasy feeling in reading the paper that the title was a little too broad. What the tests really cover is the protection of hot-rolled structural steel, which is rather a different proposition from other kinds of steel. Hot-rolled structural steel is a heavy-tonnage product; moreover, the surface of the steel is of a rather coarser type than is found with other types of steel. I think, therefore, that what we shall look for principally in the paper is as much information as we can get on the cheaper types of material, such as, for instance, zinc, aluminium, and lead. Dr. Hudson has anticipated me to some extent by his remarks in presenting the paper. In addition, the scarcer materials, *e.g.*, cadmium and tin, are not of such great interest in connection with the problem of structural steel. In fact, I think that encouragement should be given to the use of those rather crucial metals in other connections than on high-tonnage material.

A good deal of detail is given on the rather special or crucial metals such as cadmium and tin, but I do not think that where cadmium is concerned the conclusions alter that which has already been established, namely that in an industrial atmosphere cadmium is inferior to zinc. What we really want to

know as regards cadmium and zinc is their relative behaviour in the milder atmospheres, and for that purpose we shall have to wait a little longer.

My own view is that the principal value of the paper lies in the further information which we have on zinc. There what we principally wanted some scientific information upon was how spraying behaved when compared with the older processes of hot-dipping and electrogalvanizing. Previous work had gone a long way to establish that the older methods were equivalent on a basis of thickness to thickness, but now we know that we can couple with these the spray coating as being equivalent on that same basis, and also to some extent the sherardized coating, which is another coating about which we wanted to know the answer, and the authors have given it to us.

On the other one of the trio of metals, aluminium, the information given in the paper is very important indeed, because by contrast with zinc it certainly looks as if the method of application of the aluminium coating will control to a very large extent its protective value. In particular, the authors say that the hot-dipping process is very distinctly inferior to the spraying process.

Although I have listened with great attention to what the previous speakers have said, I feel that there is an element of criticism in regard to the strictures passed on the powder method, in view of the plain fact that a powder containing 3% of copper was used. We were badly wanting to have a clear issue as to the actual behaviour of aluminium put on by the powder pistol relative to that put on by the wire pistol, but I am afraid that this paper does not convince me. There may be a difference, but I do not think that the paper brings it out, because the authors have used a different material in the comparison.

Another point which perhaps is not made as much of as it deserves is the supreme value of electrodeposited lead coatings in industrial atmospheres. Going through the tables, I find that a lead coating of 1 mil (*i.e.*, 0·001 in.) thick has lasted better than any other metal at that thickness, and that recalls the fact that it is on record that the German State Railways before the war used lead coatings for some of their bridges. I myself conducted tests on electrodeposited lead coatings in pre-war days which were very encouraging, in particular in relation to the point which the authors make about the porosity of coatings. They go rather a long way on porosity, and condemn pores in coatings very freely in cathodic coatings, largely, I think, because they find that a lead coating in sea-water gave very bad pitting. That does not mean that the same situation will arise with a lead coating on steelwork.

Dealing with electrodeposition, the authors say on page 247 of their paper, in effect, that it has an advantage over other methods in permitting close control of coating thickness. That is scientifically true, but I think that it is not altogether in line with practice. In my opinion the statement is a rather surprising one, because the criticism generally levelled against these coatings is that they do vary in thickness on account of the well-known current-distribution effect, and attention has to be paid to that in practice. The matter is in the course of being seriously studied from that point of view. I do not know how far the development of methods of local thickness testing has contributed to that, but the development of such methods whereby we can test the thickness of a metal at any spot, began, I think, about the year 1933, under the wing of the Electrodepositors' Technical Society. That work had the effect of making people begin to realize the importance of thickness, which Dr. Evans has explained so well to-day.

I hope that I have not appeared to be unduly critical, because I think that this is a very good paper and will probably become famous. If attention is directed to one or two points in a discussion of this kind it does not detract in any way from the value of the paper.

I have also read Mr. Fancutt's Report very carefully, and this too I think is going to be famous; it will be kept on the shelf and referred to by many people from time to time. There is one point which struck me, and which ought to be mentioned in connection with the author's conclusions regarding the difference between methods of cleaning. His conclusions, if I understand them aright, are that you must get the metal clean and that it does not really matter what method you use to get it clean. From my own experience, however, I think that there will be a difference, and that it will depend on the painting and the paint used. If you look at the table of results you will find that the author's two paints were the relatively good, robust, thick sort of paint coatings which would be representative of very good practice. If you think for a moment of the configuration of the surface underneath, you will appreciate that as the surface is made rougher and rougher so a time will come when the paint will not be able properly to cover the peaks of the small mountains on the surface. If, therefore, you wish to use a good method such as shot-blasting, you can do so only if you know you have a sufficient thickness of paint coating on it. If the paint coating is thin for any reason, as might happen when using a higher-quality finish and not so much of it, you will very likely find that you will get premature failure. I have met with two examples of that, and I think that it is something about which a word of warning is required on the preparation side, especially where methods which involve roughening of the surface are recommended.

Dr. **T. P. Hoar** (Cambridge University): I am greatly interested in these two papers; we owe the authors many thanks for bringing forward this definitive work at the present time. If I have one or two criticisms of Dr. Hudson's and Dr. Banfield's paper, they scarcely detract from my admiration of the authors' hard work and usually clear-cut results.

My first point concerns paint coatings on top of zinc. The authors have rightly pointed out the good protection given by paint coatings with zinc undercoats, and it is a pity that their results depend on the exposure of specimens well coated with zinc but with a top coat of an unsatisfactory, deteriorated

paint. No one knows better than the authors the importance of a proper choice of paint, and it is most unfortunate that the experimental paint did not conform to good practice. I emphasize this because the authors seem to question, on the basis of their experiments, whether it is in general desirable to paint on top of zinc, owing to the doubtful nature of the adhesion. It is now well known that sprayed zinc coatings, and properly prepared galvanized coatings, can be painted with complete satisfaction provided that the paint is suitable; to raise further doubt in the matter on the basis of these admittedly unsatisfactory experiments is a little unfortunate.

Another case where the experiments and conclusions seem to have gone wrong is the comparison of the powder-sprayed *impure* aluminium coats with the wire-sprayed *pure* metal. Here again, I believe too definite conclusions have been drawn from unsatisfactory experiments.

We may consider the general question of whether results of unsatisfactory experiments should be reported or not. If one reports them, as the authors have done, one should surely draw no conclusions but merely say: "Here is an experiment less well arranged than we intended; make what you can of it." This may indeed be the best policy, for if one does not report such experiments somebody is bound to say: "Why did you not put that matter in? I know you have the results and you are concealing them." But the danger in the reporting and commenting on unsatisfactory data is that those who are not experts in the subject may easily be misled if the comment is any but the most conservative kind. In the present case, the authors' somewhat too sweeping comments may, for example, make an engineer very doubtful whether he should *ever* paint on top of zinc, and, furthermore, may convince him that aluminium can never be sprayed successfully by the powder process, but, as Dr. Clarke has pointed out, the experiments give no real evidence on either point. Doubtless in any further work the authors will use a good paint on top of zinc, and test a powder-sprayed coating of *pure* aluminium.

In the circumstances I feel that, as regards painted zinc-sprayed coatings, our best evidence at the moment is in the large-scale practical experiment referred to by Mr. Rivett; I shall take an early opportunity of looking at the Menai Bridge, and shall follow its future behaviour as closely as I can. Mr. Ballard's lock gates, although unfortunately not in this country, seem also of very great interest.

I feel that the comparison between the powder pistol and the wire pistol has always been based on somewhat unsatisfactory evidence such as we have had this afternoon. I think it would be an excellent thing if Mr. Rivett and Mr. Ballard could get together and, each using his own pistol, spray 100 sq. ft., so that we could agree at least on which process is the faster. With regard to the relative protective efficiency of the processes, it is clear from Dr. Hudson's and Dr. Banfield's paper that there is equality in the case of zinc; further carefully arranged work is necessary before a decision can be made regarding aluminium.

Mr. **T. H. Turner** (London and North-Eastern Railway Company, Doncaster): I should like to draw two inferences from this work, because this is a meeting not of a committee but of the Iron and Steel Institute. The treatment of strip and sheet is something to which the industry must turn its attention. If we look back over the years—as I am tempted to do, because I am sitting next to Mr. W. E. Ballard, and it is over 22 years since we read a paper on metal spraying—wires were being galvanized by the hot process. In those days I tried to show that steel wires should be galvanized electrically, because that process gave a more uniform and purer coating, which is one of the points which Dr. Evans has been making. In the wire industry electrogalvanizing has by now become the rule for large tonnages. It is time that the steel industry turned out large tonnages of steel strip and steel sheet equally well protected by a uniform coating of zinc.

That is the first inference I wish to draw from this work. Zinc coating is better than paint, despite the good protection which can be given with Mr. Fancutt's pretreatment and the best coatings of paint.

The second inference I wish to draw relates to large structural steelwork. For the building of the new House of Commons, for instance, some authority must specify the treatment of the structural steelwork. What are they to do with the joists? We hope that the building will last a long time. Can we from this meeting make any useful recommendation as to what should be done with such joists? Steel users are frustrated. They read recommendations as to pretreatment and go to the steel industry for descaled sections, and are told that these cannot be produced. If this research work means anything, the steel industry must be in a position to let the engineer have descaled or zinc-coated steel, because the engineer cannot easily set up sand-blasting or pickling baths on the spot.

Mr. **W. J. Nicholls** (Central Electricity Board, London): The Central Electricity Board use steel towers, of which there are 30,000 or more scattered over England, Wales, and Scotland; some of them have been up for sixteen or seventeen years, and others have been put up more recently. All the towers are galvanized with a zinc coating of 2 oz./sq. ft. by the hot-dip process, except for about 1000 which are made of copper-bearing steel and painted.

Our experience with these galvanized steel towers confirms the information and figures for zinc coverings given in the paper by Dr. Hudson and Dr. Banfield. We find that the galvanizing in industrial districts breaks down fairly completely in between seven and ten years. That confirms the estimates given in the paper, but I think that it would be interesting (though it would be a long-term experiment) to choose one other station in a particularly good atmosphere to see how long galvanizing will last. The three stations already chosen are in an industrial district, a sea-coast district, and a very wet district in Wales. If we could have a station in East Anglia, well away from the sea and industrial pollution, we should

then know the optimum life of galvanizing under good conditions.

I am hoping that the valuable information given in this paper will be widely published and supplemented later on by a further report showing the results of galvanizing after ten years or so. I also hope that the samples will be extended in some respects. I have heard something of a zinc–tin alloy protection; I should like to know if further samples could be tried to see how the alloy compares with the pure zinc protection.

Another use which we make of galvanizing is for steel core of the conductor wires. This is a thinner coating in accordance with B.S.S. 215 and is usually hot-dipped, though it is sometimes electrolytically applied. Those coatings vary considerably in behaviour, but it is rather a special case, because the steel wires are covered with one or two layers of aluminium wires. We find that in industrial districts galvanizing outlasts the aluminium, which is corroded in ten to twelve years, but in sea-coast areas the galvanizing is the first thing to break down, after a life of seven to ten years.

Mr. **J. Ireland** (Tin Research Institute, Greenford): I should like to express my appreciation of these papers, and I realize the enormous amount of work which has gone into them. I should like to ask Mr. Fancutt in particular some questions, as I became a little "bogged down" in reading his paper. In Table VII, when discussing the use of 10% hydrochloric acid, I found that the samples which were labelled "bad" were also the samples that were rather thinly coated with paint; the bad samples had an average of 33·7 g. as against an average of 40 g. for the list as a whole, excluding those labelled "bad." I found the same thing in Table XXV; comparing the three best performances and the three worst, the amounts of paint used are 48, 48, and 46 g. as against 34, 32, and 31 g. Perhaps I fail to understand the Report, but I could not get past that difficulty, and I should like to hear from the author how he managed to exclude it in drawing his conclusions.

The part of the paper by Dr. Hudson and Dr. Banfield which interested me most was the discussion of painted metallic coatings. I think that these two papers, coming together, force one to emphasize the fact that corrosive processes under all these conditions are very different. We have found in particular that the corrosion of a metal surface under paint is entirely different from the corrosion of a metal surface when there is no paint there. The choice of protective metal coatings in this paper rather suggests that it was felt that highly protective metal coating plus paint would give something substantially better than the protective coating alone, and would in fact give the sum of the two results. It was assumed, quite reasonably at that time, that one and one would make two, but that is not always the case. As far I can judge from the paper, which is an interim report, the time at which it was necessary to repaint a zinc-coated surface was only a few months longer than the time at which it was necessary to repaint a plain steel surface, and therefore it could not be said that the highly protective zinc coatings had given full value for the money.

We have been doing some work on the use of tin in similar circumstances, and we were perhaps a little surprised to find that although tin is considered rather an inferior protection on steel without paint, with paint it does give a surprisingly good result. Our work has been going on for only a few years, and we have used a variety of accelerated corrosion methods as well as unaccelerated exposures. We have used external weathering combined with occasional salt spray as being a justifiable combination, but not necessarily the best one. Under these conditions the tin coating on steel under paint has given extraordinarily good results as compared with any form of zinc or aluminium coating. With zinc or aluminium coatings under these conditions of exposure you get a fairly heavy corrosion product which breaks up the paint film. Possibly that is not equally true under slower corrosion conditions, but our unaccelerated tests have not gone forward very far.

I think that the future of this work will undoubtedly be along the lines of using other metals to protect the steel, either as coatings or as ingredients in the paints, and that they will give a very much greater length of life than any type of preparation applied to plain steel. The effect of having lead ions close to the steel as compared with iron ions is interesting. It is reported in Mr. Fancutt's paper that the type of rusting is different. There has also been some interesting work done with zinc and zinc salts, and it is, I think, along lines of that kind that important progress will be made.

The authors have been working on these tests for five years, and many of their results are still reported as incomplete. I hope that at the same time there has been some check-up on the results of accelerated tests under similar conditions. So many specifications now call for a short, quick test, and so many decisions have to be made on relatively short-time trials, that it would be very valuable if the results of short-term tests could be correlated with these long-term tests.

Mr. **E. J. Bond** (Goodlass Wall and Lead Industries, Ltd., Liverpool): I have read the papers with considerable interest, but have not come to the meeting prepared to speak at length. From my experience of paint manufacturing, there are some points on which I may be able to elaborate. One speaker was rather critical concerning the choice of paints used by the authors as being just ordinary quality paint. The answer was that the paints were of the type commonly used for painting structural steel and were suitable for the purpose. The importance of surface preparation, as demonstrated by Mr. Fancutt, has been emphasized for many years in the paint industry, and there is no alternative to thorough removal of rust and scale previous to painting. Failure to observe this precaution has led to very many complaints and arguments, but the paint manufacturer's reply is to the effect that the work had not been properly executed and he was not responsible.

Other speakers have emphasized the desirability of steel manufacturers treating steel before leaving

their works, or of engineers providing such facilities on a site. If this could be done the life of painted structures, and the periods between repainting, would be prolonged. In fact, the life of properly surface-prepared, painted, and adequately repainted steel structures is almost indefinite, and I believe that the Menai Bridge can be quoted as an example. These results were previous to metal spraying, hot-dipping, or other methods of applying metallic undercoatings. The important factor is a coating of adequate thickness with satisfactory physical properties such as elasticity, adhesion, and degree of impermeability to moisture and weather resistance.

The **Chairman**: As the steelmaker has been mentioned on two or three occasions, I wonder whether Mr. Burton would care to wind up the discussion?

Mr. **H. H. Burton** (English Steel Corporation, Ltd., Sheffield): I have no very close practical experience of the painting of structures. The Chairman has referred to steelmakers, but my own firm has nothing to do with structural steel whatever, and consequently I cannot say very much about it. There is one thing that I would point out, however, and that is that the wholesale pickling of large structural members seems to me to be a very formidable task. It would involve an enormous outlay in the first place, and I cannot help wondering whether it would actually be practicable; the pickling tanks involved would, I think, be very difficult propositions. Probably some form of large-scale shot-blasting would be better.

With regard to the paper by Mr. Fancutt, which I think in some respects has hardly had adequate discussion, I found his very careful analysis of all the variations that he has tried most interesting and valuable, and I think that he has done a very great deal to emphasize the importance of the initial preparation of the surface. It did surprise me, I must confess, to find that he got such good results from specimens which had been descaled but subsequently slightly rusted. Perhaps he would say in his reply to the discussion whether he has any idea of what the moisture content of the rust was, whether it was particularly wet rust or particularly dry rust, and whether, having got that rust, there was any subsequent scratch-brushing; I was not clear on that point.

The paper by Dr. Hudson and Dr. Banfield I also found very interesting, particularly in connection with the comparison between electrodeposited, hot-dipped, and sprayed coatings. There is one matter to which I could find no reference in the paper; I do not know whether the authors can say anything about it. There does not seem to be any reference to the quite modern method of electrodeposition followed by remelting of the coating. Although we are not engaged in that particular trade, I have seen something of it both in this country and in America. The Americans told me that they were still not sure whether the much thinner coating—it may be a very uniform one—which they obtain in that way would give the length of life of an ordinary hot-dipped coating, which is presumably of greater average thickness, though the variations may be greater.

The **Chairman**: The authors are to be thanked for their papers, and it is fortunate that the two papers should have been submitted together for discussion. The sort of work described necessarily goes on for a very long time, and it has been suggested that, even so, the tests should have gone on for much longer. Sometimes results of the kind in question do not obtain the public discussion which they deserve.

The Chairman then proposed a cordial vote of thanks to the authors, and this was carried with acclamation. The meeting concluded with a vote of thanks to the Chairman, proposed by Dr. U. R. Evans.

CORRESPONDENCE

Mr. **A. Härlin** (IVA: S Korrosionsnämnd, Ingeniörsvetenskaps-akademien, Stockholm) wrote: Judging from the results obtained until now from our Swedish investigations, the paint thickness seems to have a marked influence on the protective power of the paint. Such an influence can also be traced in Table XXIV of Mr. Fancutt's Report, the two specimens of every pair being compared. For instance, panels 25 and 26 have gained the merit figures 1 and 39 (difference 38), corresponding to the paint weights 42 + 14 = 56 and 26 + 13 = 39 (difference 17). In this way 194 pairs have been examined, with the result shown in Table A. It may be seen that in a great majority of cases the correlation is positive.

In Table B we have extracted from Table XXIV a number of series, each consisting of two sprayed specimens and two brush-painted ones. The sprayed specimens have a greater total paint weight throughout than the others, and a greater protective power as well. In Table C some data are given for a few small series of ours. These data show the variation of the protective effect with different methods of painting, *viz.*, both coats brush-painted, both coats sprayed, and primer brush-painted and finishing coat sprayed. As a rule, the sprayed specimens here have a lesser total thickness of paint than the brush-painted ones and show a greater deterioration, *i.e.*, an inferior protective power.

These results being combined, the conclusion can be drawn that the paint thickness obviously has a greater influence on the protective power than the method of painting. As a matter of fact, we have

TABLE A—*Differences in Order of Merit and Total Weight According to Table XXIV*

Difference in Mean Order of Merit	Difference in Total Weight		Number of Cases of:		
	Min., g.	Max., g.	−2g. and down	−1 to +1 g.	+2g. and up
1–2	−9	+18	24	25	36
>2	−6	+20	19	24	66
	TOTAL:		43 + 49 + 102 = 194		

TABLE B—*Series Extracted from Table XXIV*

Panel No.	Method of Painting	Weight, g.	Mean Order of Merit	Panel No.	Method of Painting	Weight, g.	Mean Order of Merit
	Group D *Steel* X *Paint* G				*Group* S *Steel* T *Paint* G		
79	Spray	12+26=38	18	345	Spray	13+30=43	18
80	,,	10+25=35	24	346	,,	14+31=45	21
114	Brush	8+21=29	57	343	Brush	9+23=32	26
113	,,	7+19=26	69	344	,,	10+21=31	29
	Group D *Steel* X *Paint* H				*Group* S *Steel* Z *Paint* G		
82	Spray	34+17=51	8	355	Spray	13+30=43	8
81	,,	36+17=53	17	356	,,	14+28=42	14
116	Brush	27+10=37	46	353	Brush	8+21=29	24
115	,,	22+ 8=30	55	354	,,	9+20=29	33
	Group D *Steel* Z *Paint* G				*Group* S *Steel* X *Paint* H		
133	Spray	14+26=40	9	370	Spray	46+15=61	1
134	,,	11+24=35	15	369	,,	50+17=67	6
125	Brush	9+21=30	51	365	Brush	30+10=40	15
126	,,	7+15=22	52	366	,,	32+10=42	16
	Group S *Steel* W *Paint* G				*Group* S *Steel* X *Paint* G		
341	Spray	12+34=46	17	371	Spray	13+30=43	23
342	,,	14+28=42	22	372	,,	15+27=42	26
340	Brush	10+25=35	30	368	Brush	10+23=33	37
339	,,	9+23=32	34	367	,,	10+23=33	38

TABLE C—*Data for Writer's Series*

Weathered and Machined Specimens					Pickled Specimens				
Panel No.	Method of Painting	Thickness, μ	Deterioration (f)	$\frac{\mu^3 f}{1000}$	Panel No.	Method of Painting	Thickness, μ	Deterioration (f)	$\frac{\mu^3 f}{1000}$
		Paint G2T22 (*Klint-Bernhardt*)							
2120	B + S	27+56=83	33	228	120	Brush	32+42=74	48	263
110	Brush	27+33=60	79	284	2115	Spray	21+42=63	72	285
2110	Spray	26+22=48	127	292	2125	B + S	31+57=88	44	340
		Paint G2T39							
2121	B + S	25+14=39	94	143	2116	Spray	30+17=47	114	251
1113	Brush	24+39=63	44	175	2126	B + S	31+37=68	56	259
2111	Spray	27+18=45	93	188	2106	Brush	27+37=64	81	331
		Paint G4T22							
2112	Spray	24+27=51	47	122	2117	Spray	31+27=58	34	114
2122	B + S	27+25=52	99	267	2127	B + S	31+21=52	67	181
112	Brush	24+35=59	94	327	122	Brush	32+35=67	50	224
		Paint G4T39							
2113	Spray	22+19=41	65	109	2128	B + S	34+17=51	49	127
2123	B + S	30+11=41	68	114	2118	Spray	25+20=45	75	152
115	Brush	33+34=68	31	143	125	Brush	36+38=74	36	197

found it proper, within the actual range and rather approximately, to count upon a *quadratic* relation between paint thickness and protective power. The product $\mu^2 f$ in Table C, μ being the thickness and f the deterioration, then should give a measure of the true deterioration for a standard thickness. According to these values, brush-painting as a rule should be inferior to the two other methods, but the tendency is not constant. When the individual $\mu^2 f$ values in each group are compared with the mean of the three values, four-fifths of the values deviate from the mean by a maximum of 20%, while if the f values themselves are treated in the same way only one-third of them fall below 20% deviation.

The deterioration figures here mentioned are based on readings once a year, according to our ten-degrees' rusting scale. If the "painting value" is noted to be 8, the "deterioration value" will be $10 - 8 = 2$. If, for example, the figures are 2 the first year, 3 the second, and 5 the third, we thus obtain: $f = 1 \times 2 + 2 \times 3 + 3 \times 5 = 23$. The f values in Table C in this manner sum up eight years' readings, each being the mean of six surfaces and the observations of two examiners. This calculation, of course, is merely a provisional one, allowing us numerically to compare even slightly deteriorated specimens. The definite estimate of a certain specimen will be based on the curve from the painting values year for year, the time for the curve to reach the value 5 being considered as the lifetime of the paint.

Far greater differences are obtained between the different paints than between the painting methods. The combination *G4T39* thus is decidedly better than *G2T22*, and the two "crosswise" combinations often give values in between.

As to the pretreating methods, Table C permits no clear conclusions for the two methods cited. These specimens are exposed in Stockholm, in a "medium" climate. In more mild climates the pickled specimens have proved to be decidly better, while a contrary tendency has been noted in salty climates. Sand-blasting (up till now only tested in Stockholm) seems to be better than pickling and decidedly better than weathering or machining. The deterioration increases very markedly with the degree of weathering before machining and painting, but not at all in the case of weathering before sand-blasting and painting.

Mr. **R. L. Frost** (Messrs. Thos. Parsons and Sons, Ltd., Mitcham, Surrey) wrote: From the summary of results shown in Table XIII, p. 32, of Mr. Fancutt's Report, on comparing the behaviour of paint processes *G* and *H* on clean and rusty surfaces it is clear that on rusted surfaces the performance of painting process *H* is very much better than that of *G*. But on clean surfaces, although the average result shows that the two processes provide about equal protection, nevertheless certain unevenness of behaviour is evident.

From Table XIII it appears that on pickled surfaces process *H* has given slightly better results than process *G* (33 against 27), while on mechanically cleaned surfaces process *G* appears to have given better results than process *H* (8 against 2). I should like to ask whether the variation in the relative performance of processes *G* and *H* on clean metal can be explained, and also whether Mr. Fancutt would deduce from his results that process *G* gave better results than process *H* on mechanically cleaned surfaces and that process *H* gave slightly better results than process *G* on chemically cleaned surfaces.

Although it is appreciated that the work was undertaken to compare the effects of different methods of pretreating iron and steel, and that the assessment of paint behaviour was concerned with painting systems and not with the individual performance of red-lead paint and red oxide paint as priming coats, it seems that a more satisfactory comparison of the behaviour of these paints as primers could have been made if the same finishing coat had been applied over them. Also it seems to me that the visual comparison of the degree of rust formation on the paint films was not made more easy by the use of finishing paints of different colours, particularly since one of the paints was red oxide, on which the degree of formation of rust would be somewhat more difficult to assess than on a dark battleship-grey paint.

These points are mentioned as being of possible interest and are, of course, not intended as a criticism of the very excellent work which is reported in the paper.

Dr. **W. H. J. Vernon** and Mr. **R. St. J. Preston** (Chemical Research Laboratory, D.S.I.R., Teddington) wrote: The vast amount of experimental work that Mr. Fancutt has embodied in his Report makes it a veritable compendium of information on a very topical practical problem. That the proper preparation of steel for painting is one of the most important factors in protection against corrosion has not been sufficiently realized in the past; here, however, the problem is treated with the respect and with the adequacy that it deserves.

The scope of the report almost inhibits detailed comment, but a few general observations may be offered.

The conclusion emerges clearly that the provision of a uniform coherent surface is the objective at which to aim for satisfactory painting. Not the least welcome feature of the paper is the satisfactory manner in which it clears up a number of points on which hitherto there has been much uncertainty; this is particularly true with respect to the influence of rust or scale on the metal previous to painting. It is interesting to note Mr. Fancutt's conclusion that there is no appreciable difference between the adhesion (durability) of the paint coating, whether applied to the scale-free or to the scale-covered steel, provided that the envelope of scale is unbroken. This is in line with experience at the Chemical Research Laboratory in respect of much thinner films of oxide produced by chromate treatment (the beneficial effect of the passive film appears to be directed entirely to the prevention of rust, the film itself having a negligible effect on paint adhesion), and is also consistent with the author's observation (p. 29) that the effect of storage after pickling is

negligible so long as the formation of surface rust is avoided. Clearly, the selection of inhibitors for use in acid pickling must be influenced by the desideratum of a film which, besides preventing rusting previous to painting, will actually increase the adhesion of the paint coating itself.

Pickling processes, with which the author has dealt extensively, appear to be satisfactory if properly controlled, *i.e.*, if the activity of the acid is maintained. As the author feels that the steel industry is not fully equipped or attuned to pickling as an integral part of their manufacturing processes, it would have been of interest to know the useful " life " of pickling baths with a view to encouraging the use of continuous processes, such as are in operation in the phosphating industry.

The efficiency of the organic inhibitors used at a concentration of approximately 0·003% appears very high : these concentrations are much lower than we are accustomed to use in the laboratory, and we should be interested to know whether they maintain their inhibitive effect throughout the process of pickling (the hypothetical mechanism of inhibition requires sufficient inhibitor to be present to form a blanketing film).

The results of exposing panels representing various pickling treatments previous to painting are of obvious value ; as a matter of interest, we should have been glad if the tests could have included corresponding unpainted " control " panels after pickling alone.

The removal of scale by weathering is obviously the simplest and cheapest process, but is inefficient and restrictive of the flow of material to manufacturers. The uncertainty of this process is clearly demonstrated by the author when he shows that a period of three months is quite effective at one time in descaling and quite ineffective at another. This is a case where the process of outdoor weathering to remove scale might well be hastened artificially. The average English summer is probably good weather for descaling, and it should not be difficult or costly to arrange for periodical supplementary spraying.

Referring to the paper by Dr. Hudson and Dr. Banfield, Dr. Vernon and Mr. Preston wrote : At a time when the necessity for efficient protective measures for iron and steel has become of high importance this authoritative publication is very opportune. The authors rightly refer to the absence of any comparable systematic investigation covering so wide a field ; particularly gratifying, and probably unique, is the large amount of information on the mode of application, analyses, etc., which is given concerning the coatings the corrosion behaviour of which is under review.

The fact that the authors have been able to plot curves showing the relationship between life and weight of coating is of itself important and valuable. Some doubt arises, however, about the precision with which the data permit the evaluation of the slope of the straight lines in Figs. 20, 21, and 22 (in Figs. 20 and 21 it would seem that the graph could reasonably have been drawn through the origin), and hence about the significance to be attached to the intercept on the vertical axis and to the constant in the corresponding equation.

Turning to particular coatings, it is noteworthy that heat-treatment of the hot-dipped coatings of aluminium reduced the protection afforded. Information on the mode of heat-treatment and the authors' interpretation of the result would be welcomed. Comparison of the effects of heat-treatment of zinc coatings will be awaited with much interest. The authors conclude that the method of application, *per se*, has considerable influence on the life of the aluminium coatings, but very little in the case of cadmium and zinc ; it is clear, however, that much more evidence is required before this can be regarded as a generalization. In particular, the evidence on this point in respect to cemented and hot-dipped coatings of cadmium and zinc (Figs. 21 and 22) would seem to be very meagre. Naturally, this is not surprising, in view of the difference in thickness that normally obtains in practice between the two types of coating.

The authors' findings on the relative behaviour of cadmium and zinc as coating materials usefully clarify the position, on which there has been much confusion in the past.

With regard to the electropositive metals, lead and tin, a little more emphasis might perhaps have been placed on possible effects on the basis metal, particularly in respect to thickness. It seems not improbable that if specimens of thin sheet had been substituted for the $\frac{3}{8}$-in. plate the basis metal might have undergone perforation before the coating had technically (*i.e.*, on the authors' method of appraisal) " failed."

On general grounds (especially bearing in mind the application of the coatings for the purposes other than structural steelwork) it is to be hoped that the authors' technique may be extended to other coating metals which in the present work, for reasons given on p. 231, have been excluded.

Dr. **T. A. Banfield** (British Anti-Fouling Composition and Paint Co., Ltd., Barking, Essex) referring to Special Report No. 31, wrote : It seems that the question of surface preparation of steelwork before painting is settled for all practical purposes, but that it still remains to persuade users to apply the knowledge made available. At the recent Oil and Colour Chemists' Association conference at Buxton, surface preparation was mentioned several times and there was general agreement with the recommendations made by the Corrosion Committee ; there is no doubt then that the technical side of the paint industry is aware of the position. The architects and engineers, however, who usually specify the painting procedure to be followed, are apparently not so firmly convinced of the value of correct surface preparation. Whilst they know that a clean surface free from rust and scale is desirable, they seem loth to adopt the necessary chemical or mechanical methods, either on account of the extra initial cost, or sometimes, as Mr. Turner pointed out, because the facilities are not readily available. If they could be convinced of the long-term benefits of correct surface preparation I am sure the facilities would be forthcoming on demand. The Protective Coatings Sub-Committee have already done some

work of an educational nature by the wide circulation of their booklet on the protective painting of structural steelwork, and the series of papers given by Mr. Fancutt and Dr. Hudson to various societies in recent years are also of value in this respect in addition to their scientific merit. I suggest, however, that there is scope for much more educational and publicity work. Information of this kind must be thoroughly reliable and there must be no chance of disseminating misleading facts; on these grounds I suggest that the Protective Coatings Sub-Committee should extend their work in this direction.

Mr. **H. A. Holden** (The Pyrene Co., Ltd., Brentford) wrote: The paper by Mr. Fancutt and his colleagues is of fundamental importance to all who are directly or indirectly concerned with the corrosion protection of iron and steel surfaces by organic finishing systems and is a valuable contribution to our knowledge of the subject. By affording still further convincing evidence of the deleterious effect of the simultaneous presence of rust and mill scale under a paint film, and demonstrating that of the many surface-treatment methods tested all which leave the metal surface in a rust- and scale-free condition are comparable in producing a satisfactory surface for subsequent painting, the paper lays down what can be considered to be the fundamental principle of good painting practice. Complete freedom from rust and mill scale is not the whole story, however, and although the Report makes it clear that the various surface treatments were selected with special reference to pickling processes, and the obvious necessity for limiting the number of test-specimens narrowed the scope of the programme, in the writer's opinion a few specimens at least should have been phosphated and painted. This pretreatment method is widely used and should be regarded as one of the recognized methods of surface treatment as detailed in the terms of reference of the investigation. The proprietary phosphating processes are singularly adaptable to modern mass-production finishing methods, and in consequence are primarily used on light-gauge steel parts which normally require only degreasing and not pickling or descaling. Where the dimensions of the work are such that pickling can be carried out, improved corrosion protection of heavier-gauge material would be obtained by the inclusion of a phosphating process. The marked increase in the protective value of organic finishes when applied to phosphated surfaces and the consequent localizing of rusting at damaged areas in the paint film are now well-established facts, and a few tests on this type of surface would have greatly increased the practical value of the research.

A recent series of tests carried out at the works of The Pyrene Co., Ltd., in which over seventy 6-in. × 4-in. × 20-gauge autobody steel panels were given a variety of surface pretreatments before painting with a single dip-coating of a stoving primer (*CS* 2249), showed that after 12 months' outdoor exposure facing approximately south and inclined at 45°, there was a marked difference in the condition of the paint on the backs and fronts of the specimens. Whereas in all cases failure on the fronts was characterized by almost 100% chalking, the complete absence of blistering, and dark reddish rust spread from the edges, on the backs there was no chalking but appreciable general light brownish-yellow rust and rust staining, not concentrated at the edges. In addition, in certain cases there was marked fine blistering, so that, without exception, the back of each specimen was worse than the front. The actual results, averaged on 72 surfaces, were as follows:

	Front	Back
Chalking, %	90–100	Nil
Blistering, % ...	Nil	7
Rust and rust staining, %	8	44

A study was therefore made of the results given in Table XXIV of the Report to see whether any similar phenomenon was recorded for the tests carried out at Derby. Whilst the table does not contain sufficient detail to enable one to ascertain exactly whether at the completion of the test there was a marked difference in the corrosion-protective value of each surface, taking those specimens on which at least one surface fell within the grade, "fair," "poor," or "bad," the difference in the protective value of each surface, *i.e.*, front or back, as determined by the number of months' exposure required to reach that grading, was as follows:

Number of Specimens	Grading	Condition of Back: Equal	Condition of Back: Better	Relative to Front: Worse
398	Fair	60	117	221
291	Poor	39	153	99
162	Bad	21	97	44

It is clear from the above that in the early stages of the test the backs of the specimens suffered more rapid corrosion than the fronts *i.e.*, the number of specimens on which the back was graded "fair" before the front was almost double that on which the reverse occurred. On the other hand, however, considering those specimens which further deteriorated through the stages of "poor" or "poor to bad," the fronts then tended to be more rapidly attacked than the backs *i.e.*, it appears that with the poorly protective systems a reversal of the tendency took place. Taking this into consideration, however, it is still difficult to correlate this method of analysing the results in Table XXIV with the statement on page 19 of the Report that at the conclusion of the tests the fronts of the specimens were almost invariably in an inferior condition to the backs.

Mr. **C. E. Richards** (G.P.O. Research Station, Dollis Hill) wrote: In their paper Dr. Hudson and Dr. Banfield have managed to line up the observations of many workers on the life of zinc coatings in industrial atmospheres, and I hope that now these results may be accepted by scientists and engineers for a spell so that our efforts may be turned in other directions.

I am in qualitative agreement with the authors on the relative rates of corrosion of zinc and cadmium, though my tests have so far been confined to exposure to the suburban atmosphere at Dollis Hill and in my "industrial spray" chamber. In both cases the cadmium is distinctly worse than zinc but the ratio is not so high. I was at a loss for an explanation,

but perhaps one can be found in Fig. 19. The cadmium there has a very well-developed surface, whereas mine, which was deposited from Westbrook's bath containing turkey-red oil and a trace of nickel, had an almost mirror-like finish. The ratio of areas exposed must have been at least 2 : 1.

On p. 246, referring to the corrosion rates of zinc and cadmium, it is remarked that "the contrary view was current some years ago, based on the results of laboratory spray tests." If my recollection is right, all these tests were salt-spray tests, which were then popular, and, I think, one seashore test in the U.S.A. Laboratory spray tests in an atmosphere containing sulphur dioxide confirm the outdoor tests in city atmospheres.

I was surprised and gratified to find that chromate-dipping has been found of little use in extending the life of zinc and cadmium coating. This agrees exactly with our own findings, but the popular insistence on the use of this finish had shaken my faith in some of our work. Our own tests over a period of ten years indicate that the finish is without advantage in industrial atmospheres, though it may increase resistance of both zinc and cadmium to the salt-spray test.

Finally, on the subject of zinc coatings, the formulæ—quoted in my paper* on this subject—where $L = 2{\cdot}78t + 1{\cdot}6$ for No. 8 S.W.G. wire and $L = 2{\cdot}42t + 1{\cdot}0$ for No. 14 S.W.G. wire, which are based on rusting to 75% strength, show precisely the same average rate of $2{\cdot}60t$ which the authors find (p. 245) and which was found by A.S.T.M. for fencing wire (p. 243).

With reference to the remarks made by Dr. Evans at the meeting I agree that a full and continuous zinc coating is ideal, but I think that the protection afforded by a discontinuous one in an industrial or suburban atmosphere is greater than he suggests. An impressive, though not very scientific, test can be carried out by driving an ordinary iron nail halfway into a fencing post and winding over the exposed portion an open helix of zinc or galvanized iron wire. The nail will remain bright for quite a long time compared with a fully exposed nail, and the helix of galvanized wire does not seem to suffer much more than the straight portion of wire remote from the nail.

AUTHORS' WRITTEN REPLIES TO THE DISCUSSION AND CORRESPONDENCE

Mr. **F. Fancutt,** Dr. **J. C. Hudson,** and Dr. **T. A. Banfield** wrote in reply: In view of the inter-relationship of metallic coatings and painting systems generally, we feel that it would be an advantage to present a single joint reply to the discussion and correspondence. We should first like to thank the several contributors to these, and we are pleased to note the interest that our papers have aroused.

Dealing with the point made by Dr. Evans regarding the application of zinc-rich paints, there can be no doubt that this type of paint shows considerable promise so far as the arrestment of corrosion is concerned. We are not at all convinced, however, that the best results will be achieved by incorporating the zinc dust in polystyrene media. We feel that other paint media may be capable of producing equally satisfactory results and would add a note of caution regarding the use of polystyrene media, since evidence is accumulating that premature failure of succeeding coatings through loss of adhesion may be associated with the use of polystyrene. In our view the results obtained with zinc-rich paints generally should be judged with some reserve at this stage.

Dr. Evans also referred to the work which he and Dr. Mayne have conducted on the influence of lead soaps. We would point out that we have been studying this problem in several directions for some time past and as a result have formed the opinion that the success of paint formulations of this type is linked with the progressive formation of lead soaps in the paint media rather than with their deliberate addition as preformed soaps. We hope that the work which is at present being carried out on behalf of the Protective Coatings Sub-Committee will confirm this.

We agree with Dr. Evans' remarks concerning non-uniform coatings of zinc; it is particularly true that the method of application must be considered for articles of complicated form. In such cases, and in the case of roofs discharging rain-water on to lower roofs, attention to details of the design may improve the performance of the coating. Whilst we agree that metal-spraying processes possess the advantage that a greater coating thickness can be put on where needed, this control of thickness by the operator has a serious practical disadvantage in that very careful inspection is necessary to ensure that no thin places have been left. When an operator is hurried—say when he is being paid on a piecework basis—he will tend to leave such places, and this may lead to rapid local failure of the coating. Thin metal-sprayed coatings followed by paint will give satisfactory results provided that maintenance is good, but a thicker metal-sprayed coating will afford a greater margin of safety in case of irregular repainting.

To refer briefly to the point made by Mr. Bateson regarding bridge painting, we should like to emphasize that fully 80% of the cost of painting structures such as bridges is absorbed in labour costs. If something can be done to extend the useful life of coatings, say, from five to seven years, by pretreatment of the steel before painting, it is obvious that maintenance costs will be spread over a much longer period of time and considerable economics will be effected. To those who are interested in comparisons of various methods of pretreating steel before painting and of different protective painting schemes, the paper by Fancutt and Hudson presented to The Institution of Civil Engineers should be consulted.*

Dr. Jones asks for costs of the various processes. We do not agree that these should be included in a

* *Journal of the Iron and Steel Institute*, 1938, No. I, pp. 155P–156P.

* F. Fancutt and J. C. Hudson, "Prevention of Corrosion in Ferrous Metals." Structural Paper No. 17, read before the Structural and Building Engineering Division of The Institution of Civil Engineers on 4th February, 1947.

paper of the present sort, as they will vary from time to time and a potential user can easily obtain competitive quotations for any particular job. As regards recommendations to industry for the protection of steel against corrosion, attention may be drawn to the booklets, " Protective Painting of Structural Steel," issued by the Protective Coatings Sub-Committee of the Corrosion Committee (Iron and Steel Institute, 1941), and " Recommendations on Methods of Protection against Corrosion," P.D.420 (British Standards Institution, 1945). We agree in general with Dr. Jones' recommendations regarding sprayed metal coatings followed by paint ; there is probably little to chose between zinc or aluminium, provided that suitable paints are used, but in humid or severely industrial atmospheres we should expect better results from aluminium when properly applied.

It is unfortunate that when in 1940 we invited the Schori Company to spray some of our specimens with aluminium, a powder made from secondary aluminium was used. This only became known to us when a sample of the powder was analysed, which was not until the tests had been in progress for several years. We cannot accept responsibility for the use of this impure powder ; so far as we know the coatings were typical of the " aluminium " coatings sprayed by the Schori Company at that time. This position was unsatisfactory, and we feel sure that Dr. Jones will readily admit that there was room for improvement in the technical control over the coatings sprayed by his company. It may well be that the aluminium coatings sprayed by the powder pistol at the present time are superior to those sprayed in 1940 ; this applies to all the other testing processes, and does not alter the fact that the coatings tested were typical of commercially applied coatings at the time. The tests mentioned by Mr. Ballard in his contribution to this discussion seem to indicate that the impure powder may not be the only reason for the early failure of the Schori aluminium coatings. This view is supported by the fact that where comparisons are based on thinner coatings of the order of 1 mil, there is no marked discrepancy between those applied by the powder pistol and those applied by the other types of pistol (*see* Fig. 20). It is hard to understand why the presence of 3% of copper in the aluminium should not prove to be injurious in a coating which is nominally 1 mil thick and yet account for the bad behaviour of a coating of the same type that is 3 or 5 mils thick.

Mr. Ballard asks for a table giving the comparative virulence of typical atmospheres ; this can be deduced from Table I of the paper, with the results given in Table D. These figures are necessarily approximate, and the lives for the unprotected mild-steel sheet are calculated on the assumption that failure would occur by perforation when the average residual thickness had been reduced by corrosion to 0·04 in.

We agree with Mr. Ballard and Dr. Jones regarding the need for *measurements* of the thickness or weight of metal coatings ; in the past reports have been published comparing different metals or processes without any indication of the thicknesses applied, and the results have therefore been valueless to a careful reader.

In Dr. Clarke's contribution, reference is made to the use of electrodeposited lead coatings for the protection of steel. It may be pointed out that in connection with work started in this country some 20 years ago on lead-coated steel panelling used for railway stock, disastrous results were observed after a period of years, so far as the adhesion of the paint was concerned. It is obvious, therefore, that there is a need for further research on methods of preparing lead-coated steel for painting, and also on the formulation of paints for application to this class of material.

Dr. Clarke is right when he points out that the results to date of the tests on metallic coatings are limited to industrial atmospheres and sea-water immersion, and that in general the tests are concerned with coatings suitable for application to hot-rolled structural steel. These points are made in the text of the paper, but could hardly be incorporated in its title without making it unwieldy. With regard to the comparison between zinc and cadmium in non-industrial atmospheres, a study of more recent observations made at inspections after 6½ years shows that in the marine atmosphere of Calshot and the rural atmosphere of Llanwrtyd Wells the zinc coatings under test remain superior to comparable cadmium coatings.

Dr. Hoar raises the question of our use of an unsatisfactory paint on the metallic coatings. The paint was quite usable, and we believe the results indicate that on the whole, in the absence of special surface treatments, the adhesion of paint to zinc coatings is not so good as to aluminium or lead coatings. We agree that sprayed zinc coatings and properly prepared galvanized coatings can be painted satisfactorily, provided that the paint is suitable. The difficulties of paint adhesion to hot-dipped zinc coatings referred to by Dr. Hoar are well known, as is also the fact that exposure to the atmosphere for a period previous to painting is good commercial practice. There is little doubt, however, that a need exists today for information regarding the correct surface preparation of galvanized sheets before painting. Much can be done, where circumstances permit, by means of phosphating and in some cases by the use of suitable surface washes applied *in situ*. Such safeguards are more than necessary in applying paint over galvanized surfaces, and this fact should

TABLE D—*Effect of Typical Atmosphere on Coating Life*

Station	Probable Life, years	
	Unprotected 16 S.W.G. (0·064 in.) Mild-Steel Sheet Exposed on One Side Only	Zinc Coating (2 oz./sq. ft. of surface)
Sheffield	6	5
Llanwrtyd Wells ...	19	28
Calshot	15	15
Congella (South Africa)	13	21
Apapa (Nigeria) ...	31	83

be appreciated more fully than appears to be the case at the moment.

Our views regarding the coatings of impure aluminium applied by the powder pistol have already been indicated in our reply to Dr. Jones. We had no hesitation in reporting the results observed for these specimens, because the coatings were typical of "aluminium" coatings sprayed by the powder process at the time the tests were commenced.

We endorse Mr. Turner's suggestion regarding the extended use of electrogalvanizing for the protection of steel strip and sheet; electrotinning is now a large-scale operation, and there seems to be no reason why zinc should not be similarly applied. We sympathize with his complaint, as a steel user, that descaled sections are not easily obtained, but in this discussion Mr. Rivett, Mr. Ballard, and Mr. Nicholls have mentioned large structures which have been descaled and metal-coated, so the problem is not unsolvable.

Mr. Nicholls' figures for the lives of galvanized coatings on steel pylons are interesting, as they provide practical confirmation of our figures, and we are grateful to him for giving them.

Mr. Ireland refers to the Tin Research Institute's work on paints applied over tin or tin–alloy coatings. These protective schemes have been developed since our tests were commenced, but the Protective Coatings Sub-Committee hope to include such coatings in a further series of tests on metallic coatings plus paint. Meanwhile, it may be noted that work carried out by the London, Midland and Scottish Railway Company's Paint Research Laboratory has proved of considerable interest in this connection, but it is too early as yet for the results to be publicized in a paper of this kind.

It is agreed that some variations in the weights of paint applied occurred in the investigations recorded in Special Report No. 31; as Mr. Ireland remarks, these were particularly apparent in the case of the specimens pickled in 10% hydrochloric acid. For this reason caution has been used in drawing conclusions from these tests when differences in the behaviour of the various processes were not pronounced. For instance, on page 41 of the Report it is stressed that the differences due to the use of various acids are small, and a similar comment is made on page 42 regarding the differences resulting from the use of acid pickling processes as compared with mechanical methods of surface preparation. Whilst, however, certain discrepancies in the results may be attributable to differences in the paint thickness, it seems most unlikely that this factor would account for the marked differences observed in the durability of the various processes as regards protection, bearing in mind that the latter ranges from specimens in "bad" condition after only 20 months' exposure to specimens in "fair" condition after 68 months' exposure. Furthermore, in many cases specimens painted when rust was present on the surface possessed much thicker coats of paint than those painted in the rust-free condition, although the protective value of the painting scheme applied to them proved considerably less.

It should also be pointed out that in addition to the data presented in the tables, which were primarily drawn up to help other workers to gain a better picture of the test results, the specimens were kept under close observation for the 68-months period of the exposure test and that some of the conclusions drawn are based on observations made during this time.

These points were considered when making the final survey of the general findings drawn from the test, and there can be no doubt of the correctness of the main conclusion, given on page 34 of Special Report No. 31, namely:

> The results prove conclusively that the maximum durability of the paint process can be obtained only when the surface treatment yields a scale-free and rust-free surface.

In reply to Mr. Ireland's remarks on the difference in the type of rusting which occurred on the panels painted with the two painting processes used, it is thought that the pitting effect observed in the case of the red-lead primer is due to the acidic nature of the aqueous extract of the paint, as compared with that from the iron-oxide/zinc-oxide/aluminium paint.

Reference to the correlation between the results of accelerated weathering tests on protective painting schemes with their service performance will be found in the paper by Fancutt and Hudson to which reference has already been made.

Mr. Burton refers to the method of applying metallic coatings by electrodeposition followed by remelting them *in situ*. This process is in commercial use for tin. The electrotinned coatings applied in this way are much thinner than those included in the present tests, and the process is not readily applicable to structural steel. Coatings of this type may prove of value for protection against outdoor exposure when followed by paint, and, as already mentioned, the Protective Coatings Sub-Committee hope to investigate the matter by conducting further tests on protective schemes comprising both metallic coatings and paints.

No information is available as to the moisture content of the rust on the specimens used for the tests on the effect of surface preparation. All the specimens which were pickled and allowed to rust before painting were wire-brushed previous to the application of the priming paint.

We thank Mr. Härlin for his contribution, which will further help in correlating the work of the Corrosion Committee with that of the Swedish Corrosion Committee. We agree with him that the influence of paint-film thickness on protective efficiency is profound, and we are studying the question. It is improbable, however, that considerations of film thickness will vitiate any of the fundamental conclusions drawn from the work on surface preparation, which are based on a statistical treatment of a large number of specimens and have been confirmed in the main by years of study under service conditions.

We consider that too great emphasis should not be laid on the differences observed by Mr. Frost in Table XIII of Special Report No. 31, because of the possible effects of variations in the paint-film thickness of the different painting schemes as applied

to different specimens. It is interesting to record that this trend or irregularity was observed by the author, but no explanation of it can be advanced. With regard to the evaluation of the degree of rusting, no real difficulty was experienced, and it is agreed that the results observed for differences between the red-lead paint and red oxide priming paints should be regarded as due to differences between the painting processes *G* and *H* considered as a whole, *i.e.*, to the priming paints in conjunction with the finishing paints, and not attributed solely to the former.

If the data are considered purely from a statistical point of view, Dr. Vernon and Mr. Preston are undoubtedly correct in stating that there is no reason why the most probable straight lines drawn in Figs. 20, 21, and 22 to represent the relation between life of a metallic coating and coating weight should not pass through the origin. An explanation of the reason why they do not is offered in the paper itself.*

No uncoated pickled specimens were exposed with the painted specimens on the roof of the London, Midland and Scottish Railway Company's Research Laboratory at Derby, but it will probably suffice for Dr. Vernon's and Mr. Preston's purpose to give the average results for the rates of corrosion of small specimens of ingot iron and zinc exposed there for successive periods of one year. These specimens, which are exposed at all the atmospheric-corrosion stations of the Corrosion Committee so as to provide an index of the atmospheric pollution, measure

TABLE E—*Results of Exposure Tests on Standard Specimens*

Station	Number of Observations	Average Rate of Corrosion, mils/year	
		Ingot Iron	Zinc
Derby ...	8	5·1	0·30
Sheffield ...	13	5·3	0·67

4 in. × 2 in. × $\frac{1}{8}$ in. thick (ingot iron) or $\frac{1}{20}$ in. thick (zinc). The figures for Derby, together with those for the Sheffield Corrosion Station for purposes of comparison, are given in Table E.† It may be concluded that the corrosivity of the Derby atmosphere for unprotected mild steel is approximately the same as that of the Sheffield atmosphere.

We agree that further research is needed to clarify the position regarding the effects of heat-treatment on the protective properties of zinc coatings; as mentioned in the paper on metallic coatings this is being undertaken by the Protective Coatings Sub-Committee in collaboration with the British Non-Ferrous Metals Research Association, and it is hoped that the preparation and exposure of the specimens will be completed by the end of 1947.

Finally, we are glad to have Mr. Richards' detailed comments regarding the behaviour of zinc coatings. As he states, the results of his tests are in good agreement with the observations of the Protective Coatings Sub-Committee.

BRITISH STANDARDS INSTITUTION

Performance Tests for Protective Coatings

The British Standards Institution have recently issued a new standard, B.S. 1391 : 1947, on a "*Performance Test for Protective Schemes Embracing Stoving Paints used in the Protection of Light-Gauge Steel and Wrought Iron against Corrosion.*" This provisional standard provides the method of testing the performance of protective schemes under corrosive conditions to determine whether a desired standard is reached. The scope is at present limited to protective schemes in which a stoved paint finish is applied over metal-coated and/or phosphated steel, and is concerned with such schemes up to and including the first coat of paint.

The test is made on special test-specimens or, in a modified form, on the actual articles, and provision is made for the test-specimens to be subjected to a standard form of damage before undergoing the test.

Details are included of the preparation of the test-specimens, the method of conducting the test, and the standard of performance required.

It is hoped that use of the standard will lead to the accumulation of experience as to the applicability of the method.

* It is regretted that in the advance copy of the paper by Hudson and Banfield the equation for the most probable straight line was incorrectly given in the case of aluminium (Fig. 20). This should read $L_0 = 0{\cdot}08W + 0{\cdot}9$, and corresponding corrections have been made in the paper as published in the *Journal*. Acknowledgments are due to the Mathematics Division, National Physical Laboratory, for kindly pointing out this mistake.

† For further data, *see* Table I of the paper "The Protection of Iron and Steel by Metallic Coatings." It should be noted that the figures for Sheffield given in that table do not refer to all of the 13 observations made there; this explains the apparent discrepancy between the two sets of figures.

Discussion at
THE SPECIAL SUMMER MEETING IN SWITZERLAND
1947

THE SPECIAL SUMMER MEETING OF THE IRON AND STEEL INSTITUTE was held in Zürich, Switzerland, on Thursday and Friday, 10th and 11th July, 1947. The Report of the Meeting is given on pages 322-330 of this issue.

Joint Discussion on the Papers—

THE PRODUCTION OF IRON AND STEEL WITH OXYGEN-ENRICHED BLAST,* and ELECTRIC SMELTING† *by R. Durrer*

and—POSSIBILITIES FOR THE EXTENDED USE OF OXYGEN IN THE BRITISH IRON AND STEEL INDUSTRY‡ *by M. W. Thring*

Mr. **R. Mather** (Skinningrove Iron Co., Ltd.) said that the contributions of the two authors were valuable as showing the possibilities of further development in directions which had been under consideration from time to time for many years.

Those with fairly long memories would recall that even at the beginning of this century there were proposals for new methods of extracting iron and steel from ore in ways which completely avoided the use of the blast-furnace. Many millions of pounds had been spent in several industrial countries in that direction, but in his view no great progress had been made as compared with the situation a generation ago, and he felt that more efficient methods of extracting iron from normal ores would mainly depend on developments in the blast-furnace process.

Dr. Durrer gave some of the reasons for the expectation that a definite advantage might be found in the use of oxygen in the blast-furnace. The speaker felt that this was one of the ways in which practice would show fairly steady development, and he was hopeful that in the next ten to twenty years there would be a marked addition to the efficiency of the extraction of iron in the blast-furnace, partly by the use of oxygen in the blast and partly by such other methods as the use of high top pressures, about which information based on actual operating practice was beginning to come forward. He saw no reason why these two developments and possibly others should not be combined as further experience was gained.

Mr. Thring had referred to the difficulty of initiating the large-scale application of oxygen. The speaker believed that some very large oxygen plants had already been completed or were in process of construction at some of the American steelworks. It might well prove that before long, interesting additional information based on practical experience would be available.

It had been suggested that it might be possible to utilize for the production of oxygen the waste heat and energy of iron and steel plants. He thought that there were now very few integrated plants which had much heat and energy available for additional operations, as the methods already established were, in practically all cases, capable of utilizing all the so-called surplus gases and energy. It did not, of course, follow from this that it would not be worth while to undertake the production of oxygen for enrichment of the blast, even if an external source of energy had to be brought in.

Mr. Thring had pointed out some of the directions in which the use of oxygen for the Bessemer process would be of advantage. The speaker wished to call attention to what might prove to be a further possibility, namely, that whereas the Bessemer process at present can be applied at the one end only to very low phosphorus iron and at the other end to iron

* *Journal of the Iron and Steel Institute*, 1947, June, pp. 253–256.
† *Ibid.*, 1947, June, pp. 257–260.
‡ *Ibid.*, 1947, June, pp. 285–291.

containing 1·7% or more of phosphorus, the use of oxygen might so raise the temperature in the converter that it might become practicable to use a basic Bessemer process for the large quantities of iron containing intermediate percentages of phosphorus.

He also called attention to the use of the word "coal" in Dr. Durrer's papers. In some places it appeared to mean actual coal as we ordinarily know it, in some cases coke, and in other cases possibly carbon. He felt that the translation from the original should be carefully scrutinized, and indicated the possibility that some of the relationships indicated on page 259, between the price of coal and the price of 1 kWh. of electrical energy might have been somewhat distorted by the confusion between coal, coke, and carbon.

Mr. **E. C. Evans** (London) said that a debt of gratitude was due to the authors for their contribution to what was probably the most important subject in metallurgy today. We were entering, he believed, an oxygen age. It was not a new conception. Blast-furnace managers might remember that over twelve years ago the Blast-Furnace Committee of the Iron and Steel Federation issued a report on the possibilities of oxygen in blast-furnace practice. The conclusion to which they came at the time was that it would not pay Great Britain for pig-iron production, but that it would pay for ferromanganese or special-alloy production. That conclusion was based on (i) the price of coke at that time and (ii) the cost of oxygen from the plants then working.

Today the position had entirely changed. Coke costs had increased considerably, whilst on the other hand recent developments in oxygen production had reduced the cost of oxygen to a considerable extent. The cost of oxygen was made up of two main factors, power cost and capital charges, those factors being approximately equal. If it was possible to reduce both, the possibilities of using oxygen became much more attractive. That could be done by building big oxygen plants; the cost went down almost in a hyperbolic curve as the quantity of oxygen increased.

Mr. Thring had referred to an expenditure of half a million pounds to test whether oxygen was of any use in the blast-furnace. It was difficult for a board of directors to undertake a gamble of that kind, but there was another possibility, which was being developed in the U.S.A. The Americans had become enthusiasts for oxygen, largely as the result of a paper (which some would criticize on points of detail) by Dr. Langmuir, following a visit which he paid to Russia. That fired the American steel trade, and most of the big plants there were now testing out the use of oxygen in their open-hearth furnaces.

There were two main lines of attack. One was the use of oxygen for combustion, and in that direction a few companies had obtained some very interesting results. With oil as the fuel, almost any modification of the oil burner to allow the introduction of oxygen produced useful results, and by adding the oxygenated air or oxygen blast during the melting-down period they had been able to increase production by something of the order of 30% with no greater wear and tear on the refractories; in fact, refractory life, expressed as the number of heats, had in one works been actually increased.

When oxygen was used with a gaseous fuel, however, burner design became much more important, and he liked the idea put forward by Mr. Thring for the direct introduction of oxygen into the gas flame along the lines mentioned.

The other line of development was the use of oxygen in the bath. For low-carbon steels, that had given most valuable results, the increase in output was of the order of 25–33%. One works, which had "gone the whole hog" and introduced oxygen into the combustion air and into the bath, had reduced the time of melting, from tap to tap, from 11½ hr. to a little over 6 hr. which meant a considerable increase in output.

Using oxygen primarily for open-hearth purposes there were possibilities of producing oxygen by methods which would not involve the very big plants and the very big expenditure required for a blast-furnace. The amount of oxygen which had been used economically in the open-hearth furnace was of the order of 800 cu. ft. per ton of steel, which meant an oxygen plant of not unreasonable size. There were schemes, however, for very big oxygen plants. They thought in tons in the United States, and 500 tons per day was regarded as a reasonable size for a unit. Plants of that kind were being designed.

In all cases where big plants were being contemplated, they were depending on a low-pressure liquefaction cycle. Kapitza started that idea when in 1941 he produced oxygen with an initial pressure of a little over 80 lb./sq. in., the air being passed through a specially designed turbine. Specially designed turbines were being tested out in England, France, Russia, and the U.S.A., and there were prototypes working in each of those countries, running at efficiencies of the order of 80% upwards. That meant that oxygen could be produced with a capital cost lower than was formerly the case, with plants which could be operated by ordinary mechanics, not requiring special techniques, and with a power cost of the same order as, if not less than, that of the older systems. One plant had been built in which the air was compressed for the most part only to 3 lb./sq. in. pressure—just enough to take the air through the heat-exchange system, a proportion only of the air going through a specially designed turbine to produce the refrigeration required to obtain the oxygen. That plant should be started within a couple of months—he only saw it being built—and if it worked it offered very attractive possibilities to the iron and steel trade, particularly in Great Britain.

Dr. **Magnus Tigerschiöld** (Jernkontoret, Stockholm) compared Dr. Durrer to a prophet looking out into the future, to the time when the blast-furnace would be diminished to a low-shaft furnace and when the open-hearth furnace would not be used at all, but instead there would be Bessemer furnaces of special construction, and rotary furnaces. Personally, he had, he said, followed the ideas and the work of Dr. Durrer for many years; he knew that Dr. Durrer loved the subject and that a vast amount of thought

and work lay behind the papers which he had presented.

There was a time, Dr. Tigerschiöld confessed, when he criticized Dr. Durrer's ideas as being a little too optimistic and a little too much "in the blue." Today, however, he had much more faith in Dr. Durrer's ideas. That was because when he was in America he, like Mr. Evans, saw what was being done, and he came to the conclusion that it was now possible to make cheap oxygen in large quantities. It must also be remembered that during the war Leipzig and Magdeburg were supplied with town's gas made by the partial combustion of lignite with pure oxygen.

One fact which had not been mentioned, but which he had seen in a Canadian paper,* was that at a big plant making non-ferrous metals at Trail, in Canada, large-scale experiments had been carried out using oxygen and steam in a gas producer, and they obtained from an ordinary coke a gas of 256 B.Th.U./cu. ft. It was possible to use just an ordinary gas producer of the Wellman-Galuska type with revolving grates and get that very rich gas. This method had the great advantage that one also used the oxygen in the steam and enriched the gas in that way.

The next step must be to try to make a gas producer with a hearth where one would melt one's slag, using oxygen and steam, then put some ore into that gas producer, and then by adding more and more ore one would end up with the low-shaft furnace which Dr. Durrer prophesied. He thought that that was one line of development.

He would like to ask whether anyone at the meeting knew of anyone who was really thinking of building an oxygen plant of large size at a steelplant in Europe. He thought that that ought to be done this year.

Dr. **L. Jenicek** (Czechoslovak Mining and Metallurgical Institute, Ostrava) congratulated Dr. Durrer on the perseverance with which he advocated the use of oxygen in the blast-furnace, and especially the low-shaft oxygen furnace. It was to be hoped, he said, that Dr. Durrer would be able to prove his ideas on a larger experimental scale. He was afraid that it was impossible to predict the value of Dr. Durrer's conception without practical proof. In 1940 Dr. Durrer estimated[1] that the direct reduction of iron ore in the low-shaft oxygen furnace would consume about 1500 kg. of coke per ton of iron, and regarded this high consumption as an advantage because of the production of a gas of high quality and in great quantity. Dr. Durrer was obliged to assume a very considerable consumption of oxygen, *i.e.*, 1200 cu. m. for 1500 kg. of coke. The question therefore arose of whether the cost of the oxygen would be offset by the price of a cheap fuel.

In Dr. Durrer's famous book, "Metallurgie des Eisens,"[2] he indicated still higher consumption of fuel, and referred to 2000 kg. of coal (without indicating its quality) and 2000 cu. m. of oxygen of 80% concentration. In both publications he developed the idea of total combustion with pure oxygen, and in his experiments he found a great percentage of CO_2 when the pure oxygen was used. The explanation was that the combustion gases had such a small volume that the neighbouring layers of fuel were not heated to the temperature at which the reduction of CO_2 to CO would be possible.

A very attractive calculation was possible. The total heat needed for the reduction of iron was between 3 and 3½ million calories. For carburizing, 50 kg. of coke were needed, and 350 kg. of coke were needed for the direct reduction of the burden, from which 400 kg. of oxygen must be taken away. This 350 kg. of coke, burned to CO, gave 700,000 cal., and 350 kg. of coke burned to CO_2 gave the rest of the heat needed. Dr. Durrer even saw the possibility of burning the CO from the direct reduction, to CO_2 and hoped at that time there would be a total consumption of 500 kg. of fuel. The consumption of oxygen would have been extremely low, at about 500 cu. m. per ton of iron. Dr. Durrer, however, was obliged to abandon that idea in 1943,[3] when his new experiments showed its impossibility.

He did not abandon, however, his low-shaft oxygen furnace, but defended it in the same paper as an installation which would permit the production of a rich gas with an inferior fuel. He again estimated the fuel consumption at about 1500 kg. per ton of iron, and the need of 1000 cu. m. of oxygen.

In the present paper a new statement was to be found. A certain indirect reduction was admitted, and only 1000 kg. of coal were needed. Of this, one-fifth, or 200 kg. would combine with the oxygen of the ore, and 750 kg. must be oxidized by blowing in oxygen, about 600 cu. m. being required. Presumably these last figures were based on experiments, and it would be interesting if Dr. Durrer would give more details, especially as to the quality of the fuel and the percentage of indirect reduction. In his earlier paper Dr. Durrer spoke of coke or coal of inferior quality, but now he spoke of coal. It would be of great interest to have more exact indications of the calorific value of the fuel under consideration in the present paper. Dr. Durrer, however, again gave ground for hope, and assumed that it was possible to consume only 500 kg. of coal and 200 cu. m. of oxygen per ton of iron. Were those figures based on practical experience ?

Another problem which was not clear was the desulphurization in the low-shaft furnace. Dr. Durrer said that, provided the top-gas temperature was sufficiently high, desulphurization took place without special slag control. That meant that he still had hopes of the importance of desulphurization with silicon sulphide. In the paper, he said that in the case of desulphurization with silicon sulphide no lime-bearing slag was required, so that the choice of raw materials for smelting became much greater. That signified an attractive possibility of reduction of poor ores with an acid slag, but Oelsen and Metz showed in 1942, in a remarkable paper,[4] that desulphurization in an acid slag was possible only if a part of the silica was reduced ; in other words, if the degree of acidity was diminished. It would be, of course, of no practical importance to obtain, at the

* R. F. Mitchell, *Canadian Chemistry and Process Industries*, 1946, Aug.

basicity index CaO/SiO_2'= 0·9, iron with 0·014% of sulphur but with 7% of silicon.

In the third edition of his book, Dr. Durrer mentioned the paper by Oelsen and Metz but said that new experiments were being made for developing desulphurization with acid slag. It was to be hoped that this meant that Dr. Durrer would put forward new facts to oppose the careful statements of Oelsen and Metz. Personally, so far as the question of silicon was concerned he was afraid that it would be impossible to control its percentage at a sufficiently low level in the low-shaft furnace, and that the temperature of direct reduction in the case of oxygen-rich blast would be too high.

Dr. Jenicek did not believe that the use of oxygen in the blast-furnace would be of general interest, and the low-shaft furnace seemed to him not very possible in practice. But there were other possibilities, and in particular, its use in the Bessemer process and in the open-hearth furnace was of great interest. Moreover, the production of rich gas from an inferior coal was important. He thought that metallurgists should be interested in such gas producers as that of Lurgi, in which the oxygen was used under a pressure of 20 atm. and in which the solid fuel was completely gasified. On that point he could not agree with Mr. Thring; he thought that the possibilities were extremely interesting.

The most important factor, however, in deciding whether oxygen would be largely used was its price. It was calculated in Czechoslovakia that a cubic metre of pure oxygen produced in Linde-Frankl installations costs ½*d*. It was cheap enough for producing a good town's gas from lignite. The costs of the installation were not low. It was to be hoped that new principles of construction would be used. The famous mechanical engineering industry of Switzerland had a very large field of activity and, with such an authority on the subject as Dr. Durrer, the most agreeable surprises were not excluded.

References

1. R. Durrer : *Stahl und Eisen*, 1940, vol. 60, p. 877.
2. R. Durrer : " Die Metallurgie des Eisens." Berlin, 1943: Verlag Chemie, G.m.b.H.
3. R. Durrer, P. Lwowycz, and B. Marincek : *Archiv für das Eisenhüttenwesen*, 1942–1943, vol. 16, p. 329.
4. W. Oelsen and N. Maetz : *Archiv für das Eisenhüttenwesen*, 1942–1943, vol. 16, p. 283.

Mr. **A. G. Robiette** (Messrs. John Miles and Partners (London), Ltd.) said that the two papers were very timely, and he hoped that they would stimulate further work on the important development with which they dealt. He endorsed most heartily Dr. Durrer's remark that if an oxygen-rich mixture was used for blowing the blast-furnace it was conceivable that one would end up with a furnace which did not look like a blast-furnace at all. Personally, he thought that that implication was fundamental and that it must be realized that the use of oxygen brought in an entirely new set of physical conditions and would upset all previous ideas of what iron and steel plant looked like.

That was where the Germans went wrong when they tried to blow oxygen into the bottom of an existing Bessemer converter. They just increased the oxygen content until the refractories failed. The Americans, in his opinion, were making the same mistake in applying oxygen to existing open-hearth furnaces, where neither the process nor the receptacle was designed for the use of that medium. He did not mean to imply that no advantage would be gained by so doing, but it disregarded the fundamental advantages which the use of high-oxygen mixtures would bring to steelmaking practice.

In his opinion, the main application to steelmaking should be the blowing of pig iron with oxygen for conversion into steel. This had three advantages. In the first place, as Mr. Thring had pointed out, it was possible to melt between 25% and 30% of the total charge in steel scrap; in other words, the circulating scrap in an integrated steelworks was completely absorbed without the necessity for any other type of steelmaking equipment, so that instead of using it as an adjunct to the open-hearth it replaced the open-hearth. Then, as Mr. Mather had pointed out, any composition of pig iron could be blown, irrespective of the content of heat-forming elements. A pig iron containing only carbon had been blown with oxygen, and steel made from it. The third advantage was that low nitrogen steels were obtained; steels had been produced which were lower in nitrogen than normal open-hearth-quality material. The use of oxygen would thus enable the open-hearth furnace to be largely replaced, with an enormous saving in fuel.

He and his colleagues had been working on this process for some years, and it was proposed that they should present a paper to the Institute on the subject in a few months' time, and he did not want to anticipate its subject matter; but he could say that they had blown a number of 2-ton heats with a 90%-oxygen mixture in a period of approximately 30 min., and had produced steel, some of which had gone into commercial products. That conversion had been effected, as he had said, in about 30 min., and as a result of their experience he regarded such statements as that credited to Kapitza, of conversion in 1 min., as completely fantastic; it was only necessary to calculate the volume of gas given off in that period when blowing a ton of pig iron to appreciate what would be likely to happen to the steel. Arrangements were now being made to carry out the process on a large scale with vessels of the order of 10 tons' capacity. This would prove, he believed, to be one of the major developments in the iron and steel industry since the introduction of the Bessemer and open-hearth processes.

Mr. **A. G. Robiette** also wrote: In his paper, Dr. Durrer has made some generalizations which do not apply under certain economic conditions. In some parts of the world, particularly in India and in South Africa, cheap non-coking coals exist, whilst at the same time there is a dearth of good coking coals. As a result there is a large difference in the prices of coking and non-coking coals.

Since the low-shaft electric smelting furnace can use non-coking coals in the form of briquettes or of a carbonized product which can be termed 'char,' it can, under such conditions, be more economical to

run a low-shaft electric furnace than a blast-furnace, even though steam power is used for electricity generation.

As the coking-coal resources in some countries are becoming rapidly exhausted, it may even become an economic necessity to produce power from cheap non-coking coals and to smelt in the electric low-shaft furnace.

The alternative is to develop an oxygen-blown low-shaft furnace, as Dr. Durrer has suggested in his other paper.

Mr. **F. G. Kerry** (Canadian Liquid-Air Company, Montreal) said that if one followed the application of oxygen to the metallurgical industries for a good many years one would notice a sine curve of the interest shown in the problem ; a period with a great deal of whipped-up enthusiasm and abstruse mathematics being followed by a period in which nothing at all happened. A little over a year ago, when the Steel Company of Canada tried out its first test in an open-hearth furnace, it did not do so in order to study the mathematics or the academics of the furnace with the use of oxygen, but rather to find an answer to a very serious problem which had to be faced elsewhere also, the problem of rising production costs. Their idea was to reduce production costs by increasing the production of steel per hour and per furnace. Obviously the way to do that was to increase the charge and increase the fuel rate per hour.

To burn more fuel in a very quick manner it was necessary to use something more than just air. To enrich the air through the recuperators was not the answer ; the furnace would not stand the heat, as was proved later. If, however, one used almost pure oxygen through the burner to accelerate the primary combustion it was possible to increase the fuel rate (he was speaking at that moment of oil) by as much as 45%. This would give increased production and, speaking rather conservatively, they felt that they could increase the production of their open-hearth furnaces by at least 30%. Moreover, although the fuel rate was increased by as much as 45% during the melting-down period, there could actually be a gain in fuel. It was possible to knock it down by as much as 25%. That, however, was not always the case ; it applied to open-hearth furnaces in which 40–50% of the charge was hot metal or hot pig iron. In furnaces where one charged entirely scrap, the effect on the fuel consumption was not as interesting, for obvious reasons.

With regard to the amount of oxygen used, a very good figure to take was about 850 cu. ft./ton of steel produced, when dealing with half of cold and half of hot metal, and about 1100 cu. ft./ton for all cold-charge furnaces.

One of the most important applications of immediate interest was not so much the fusion of scrap, because this depended entirely on low-cost oxygen, but the blowing of oxygen through a molten bath for refining purposes. It has been found, after several thousand tests, that one could apply commercially pure oxygen at current prices in view of the fact that it was possible to reduce the refining period by at least one hour. Even in small furnaces of 50–60 tons it was possible to get a reduction of as much as three-quarters of an hour. One of the most interesting aspects of the matter was the fact that in countries where the charge was high in phosphorus it was possible to bring the phosphorus content down. Recent tests had shown that by blowing in oxygen there was more intimate contact between hot metal and slag, and it was possible to reduce the phosphorus to 0·006%, after starting with a very high content. It was possible to use even commercially pure oxygen at current prices, at any rate in the U.S.A. and Canada—he did not know what the prices were in other countries—and a great many steel companies there were using as much oxygen as they could get.

He agreed with Dr. Durrer that it was necessary to stop thinking in terms of oxygen enrichment and nitrogen elimination, and start thinking in terms of oxygen as applied to basic chemical reactions. It was also necessary to stop thinking in terms of applying oxygen to standard equipment ; modifications would have to be made. At the same time, it would be realized that it was not possible to take an open-hearth furnace costing about a million dollars and replace it ; steel companies were rather conservative and just did not do things in that way, so that modifications were rather slow in coming about.

In conclusion, it might be mentioned that the oxygen plant now being built in Johnstown, U.S.A., would be ready in the autumn. It is presumed that it would be used primarily for testing oxygen in blast-furnaces and would have a production of about 145 tons per day. Proposals for similar plants in Canada were also being considered.

Mr. **A. Robinson** (Appleby-Frodingham Steel Co., Scunthorpe, Lincs.) observed that the use of oxygen in steel and iron melting offered very interesting possibilities. Those possibilities depended primarily, he thought, on the economics of the process. With regard to the open-hearth process, he thought that the best opportunities of using it, and the most likely one at the moment in England, were during the melting stage of the process, the stage in the process when one could put as much heat in as one could get. He was not so impressed by the idea of the blowing of oxygen into the bath itself. If the furnace was hot enough and the charge was working well, the refining would be done almost as quickly as it was possible to control it, and in the making of high-class steels it was necessary to have a little time and very good control over the steel bath in order to get the quality demanded. To put oxygen in the bath itself might lead to making steel which was rather more oxygenated at the end than was required. It may be useful in special circumstances when a particularly low C is required.

He had been particularly interested in Dr. Durrer's suggestions regarding the future steel furnace ; he could envisage considerable alterations being made eventually, if the oxygen was cheap enough. The use of oxygen in refining of steel would depend entirely on the relative cost of the oxygen, the cost of the charge, the cost of fuel, and also, perhaps, the cost of the refractories. At the moment iron ore was used

to give the oxygen required, and that gave a certain amount of iron which was rather cheap.

The use of oxygen in the blast-furnace offered very interesting possibilities in England, because in England they had mostly very soft ores, and in many districts very soft cokes. If it was possible to have a low blast-furnace and avoid the cost of the extremely expensive pre-preparation plants which were being installed, the saving might pay for the oxygen plant.

Mr. **J. W. Reber** (Wellman Smith Owen Engineering Corporation, Ltd.) said that he had prepared some graphs showing the effect of oxygen admixtures of from 0 to 50% on the flame temperature, but unfortunately it had not been possible to show them on the screen. When working out the flame temperature of a fuel one obtained a certain maximum theoretical temperature, which, however, was never achieved because dissociations played a great part in the combustion process and increased with a rising temperature and a rising oxygen admixture. The results of these calculations indicate that with a 50% oxygen admixture, with oxygen of 90% purity, the rise in the theoretical maximum flame temperature without dissociation is about 400° C. above the maximum theoretical temperature with no oxygen admixture, and reaches the high figure of 3150° C. When allowing for dissociation the rise in temperature for the same conditions of oxygen admixture is only about 130° C., *i.e.*, from 2270° to 2400° C. These calculations have been based on work carried out by Reingold who, along with other research scientists, states that for temperatures above 2500° C. the dissociation reactions taking place were not very well known, because there were further reactions involving OH and atomic oxygen.

Figures A, B, and C illustrate the interesting fact

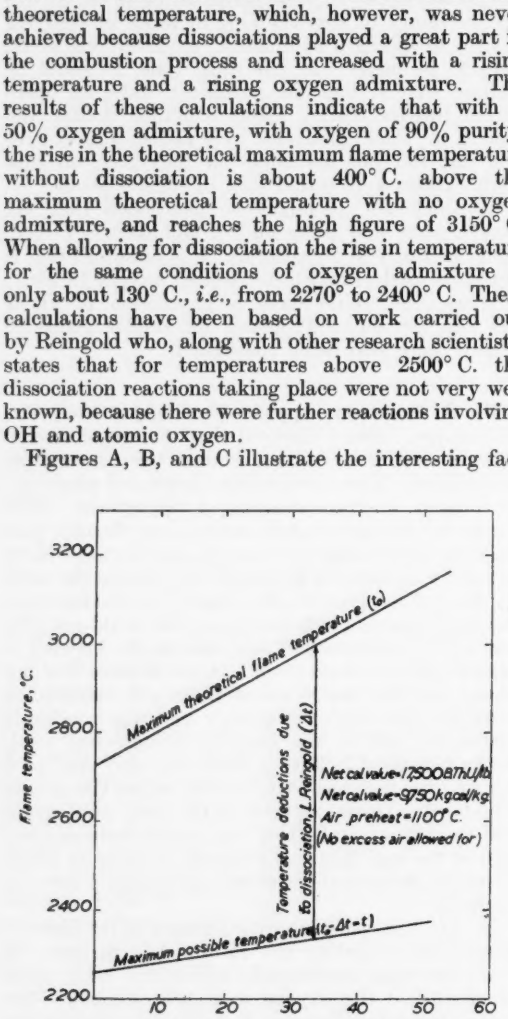


FIG. A—Maximum flame temperature with fuel oil and oxygen-enriched air, allowing for dissociation of CO_2 and H_2O

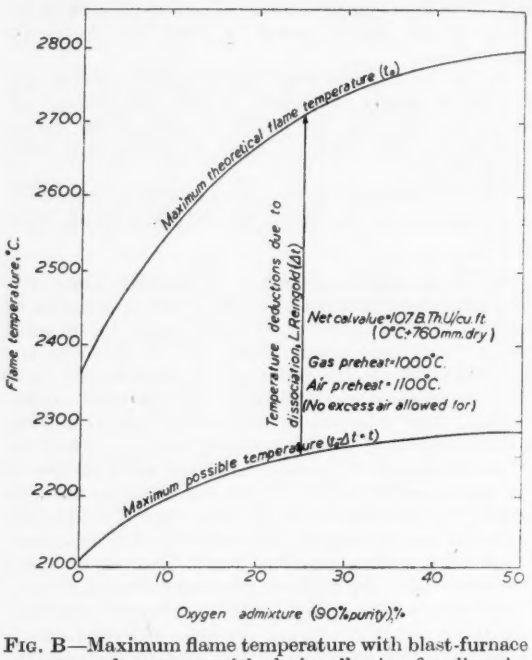


FIG. B—Maximum flame temperature with blast-furnace gas and oxygen-enriched air, allowing for dissociation of CO_2 and H_2O

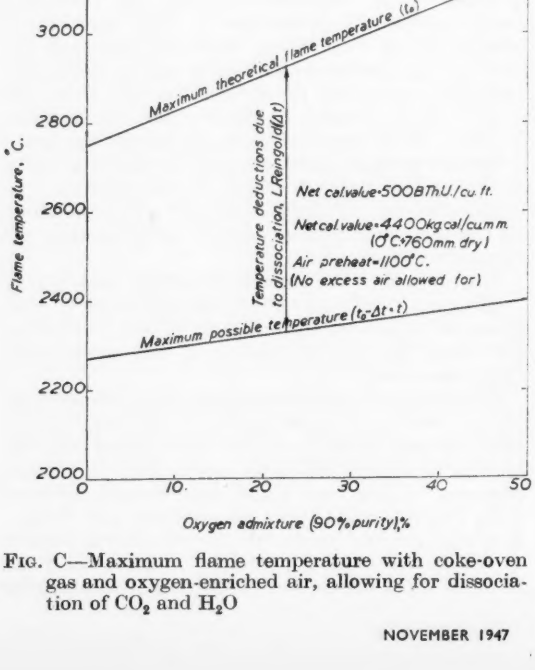


FIG. C—Maximum flame temperature with coke-oven gas and oxygen-enriched air, allowing for dissociation of CO_2 and H_2O

that the temperatures obtained either with coke-oven gas or with oil are of the same order, there is very little difference, *i.e.*, coke-oven gas with tar admixture should give the same result as fuel oil.

If an open-hearth furnace using oxygen-enriched air and fuel oil gives a higher melting rate, it can be assumed that this is only partially due to the slight increase in the effective flame temperature, but probably to a more rapid rate of diffusions, increasing thereby more effectively the actual flame temperature. In a conventional type of open-hearth furnace the actual flame temperature is only 75 to 80% of the maximum possible (effective) flame temperature, the remaining 20–25% being absorbed by radiation of the flame during the process of combustion.

When using oxygen, especially as Mr. Thring had mentioned, very close to the fuel stream, diffusion takes place more rapidly, increasing the rate of combustion with a resultant higher actual flame temperature and a quicker melting time.

The flame temperatures given in the graphs have been calculated on an assumed constant air-preheat temperature for fuel oil and coke-oven gas, or a constant air and gas preheat temperature in the case of blast-furnace gas. In actual practice it can be assumed that with a decreasing amount of combustion air, a higher degree of air preheat would be obtained, further increasing the actual flame temperature. It can further be assumed that the burner effect would be increased from 80% with no oxygen admixture, to 90% for a 50% oxygen admixture. The actual flame temperature can then be calculated by interpolations for any percentage of oxygen admixture, assuming constant preheat temperatures.

The **President** (Dr. C. H. Desch, F.R.S.) said that some years ago he had been asked by the Federation to prepare a report on processes devised for producing steel without using the blast-furnace. He had made a review of 140, of which 1 was working. Accounts of them were found in various published papers and company prospectuses. Since then a great deal of valuable work had been done on the fundamentals of smelting, and the possibility of using oxygen had become a real one, so that the subject had been presented that day from a new point of view. The bold and striking suggestions which had been made that day would be discussed with the greatest interest.

AUTHORS' REPLIES

Professor Dr. **R. Durrer**, in reply, thanked those who had taken part in the discussion, for the ideas which they had put forward. He would like especially to thank, he said, the eminent Swedish metallurgist Dr. Tigerschiöld, who had expressed himself in such an optimistic way.

Mr. Thring had professed to be a little more conservative than he himself was. Perhaps that was true, but personally he thought that it was desirable to divide the whole problem of the development of the possibility of utilizing oxygen in the production of iron and steel, into two parts—that which concerned the present time and the near future on the one hand, and that which concerned the more distant future on the other. It would be ridiculous to envisage destroying all the present open-hearth furnaces and replacing them with new furnaces. In any case those new furnaces had first to be developed, but even if they had been developed it would be nonsense to think of replacing all of the existing furnaces, because, as Mr. Kerry had said, so much capital had been invested in the existing plants. It was not possible to eliminate those plants, but it was necessary to consider how to make the best use of them. In that respect he agreed with Mr. Thring and other speakers that the tests which were being carried out in the open-hearth furnace and in the blast-furnace were of the greatest interest not only from the point of view of which he had just spoken, but because of the fact that, as Mr. Kerry had explained, production costs might be reduced and the capacity of the iron and steel industry of a country might be increased. If by using oxygen in the blast-furnace and the open-hearth furnace it was possible to increase production by 10–20%, it meant that the capacity of the iron and steel industry of a country might be increased by that amount.

The ideas which he himself had put forward related to the more distant future. He knew, of course, that there were very many difficulties to be overcome, but if one was convinced of the correctness of an idea one would not be afraid of difficulties, but would overcome them. Personally, he was convinced that it would be necessary to find another way, if the way of which he had spoken was no good, because it was not enough to think in terms of ten or thirty years, it was necessary to think in terms of centuries. The really big consumption of raw materials began only at the end of the last century so far as the iron and steel industry was concerned. During the next 50 or 100 years the consumption of iron ore and coke would go on increasing, and it would not be possible to continue indefinitely to make use of the present processes. It might not be possible to make use of these new ideas in the immediate future, but it was necessary to consider the more distant future as well, when the time would come for the present blast-furnaces and open-hearth furnaces to be replaced by others. Moreover, there were possibilities in Asia and South America, where iron and steel plants would be required in places where they have never existed before. In a few years time there might be a question of setting up new plants and new furnaces in such places.

It was impossible for him to answer immediately all the questions which had been put to him. Mr. Mather raised the question of a possible mistake in the translation of the papers as printed in the *Journal*. If there was a mistake in the English translation he must take full responsibility for it, because he had told his friend Mr. Headlam-Morley (the Secretary) that the English translation had been excellently done, and he had been through it. Without studying the text he could not say whether he had mixed up carbon and coal, but it was not by mistake that he had spoken of coal in discussing the practice of the blast-furnace ;

he referred to coal because he was speaking generally. In Sweden, for instance, they used charcoal, and in Russia they used anthracite. Perhaps 99% of the fuel used in blast-furnaces today was coke, but in addition to coke it was possible to use charcoal and anthracite if they were cheap enough, and he had wished to keep his remarks general because he was thinking not only of charcoal and anthracite but of coal of any kind. It would have been better perhaps to speak of solid fuel instead of coal.

Dr. Tigerschiöld had discussed the possibility of the production of non-ferrous metals by using oxygen. That was a very interesting problem, but it would take too much time to discuss it at the moment. Tests had been carried out over a period of about two years to purify bauxite with the help of oxygen. He himself was not concerned with aluminium, and he could not continue the tests, but it was of interest to the aluminium industry to consider whether it would be possible to carry out the purification of bauxite and the smelting of bauxite into Al_2O_3 with the help of oxygen.

Dr. Tigerschiöld spoke also of the gas producer, and said that it was a very clever idea. On the one hand there was the blast-furnace for the reduction of the ores, and if one went on eliminating more and more of the iron ore in the blast-furnace, one would end up with a gas producer. On the other hand, if one began adding more and more ore to a gas producer it would be changed in time to a blast-furnace. There was, principally speaking, iron ore in the gas producer in the form of the ashes, but only a little. By adding ore to the gas producer and by adding coal to the blast-furnace they would meet in the middle, so to speak. It was interesting to find that fuel engineers had the idea of gasifying the coal with the help of concentrated oxygen.

Dr. Jenicek had put forward some very interesting ideas, and had said that in former times he (Dr. Durrer) had spoken of the possibility of increasing the consumption of coal by using concentrated oxygen. It had been put to him as a difficulty in using oxygen, that by diminishing the amount of indirect reduction the consumption of coal would be increased, but Dr. Jenicek had put the right question by asking whether the surplus of coal or the reduction in the production costs would be the greater. It was simply an economic question.

Then there was the second stage of this development, about which he had spoken that morning in presenting his papers. In utilizing almost the whole of the calorific value of the fuel by using oxygen or electrical energy, one would decrease, not increase, the consumption of coal. If one took it for granted that all of the coal used would be burnt, resulting in the release of the whole of the calorific value, the consumption of fuel would be only 500 kg./ton when using oxygen and about 450 kg./ton in using electrical energy.

Desulphurization in the low-shaft furnace was no longer a problem. It was done in practice, and was in the first case a question of temperature. The difficulties referred to did not relate to pig iron, but only to steel.

Professor Dr. **R. Durrer** also wrote : Referring to the several questions which, for lack of time, I could not answer at the meeting, I will try to characterize in brief outline, the development of my ideas. The fundamental idea is to find a way to produce iron with any coal (solid fuel) and any iron ore. To a certain degree this is possible with the use of oxygen of high concentration, and a low-shaft furnace. If in this way the indirect reduction would practically be suppressed,* the consumption in coal would, of course, be increased. But this fact need not be a disadvantage, for the coal would be cheaper. Further, a low-grade fuel would be transferred, as far as the top gas is concerned, into a high-grade fuel, the calorific value of this gas being about three times as high as that of ordinary blast-furnace gas. The gas producers are charged with coal only. Why then could not the coal consumption be rather high in a smelting-furnace, if there is an adequate demand for the gas generated ? The reason that in the blast-furnace the coal consumption must be low, is because of the relatively high price of coke and the fact that about one half of the amount of high-grade fuel is converted into low-grade fuel (top gas).

Then came the idea of diminishing the consumption of coal by oxidizing the carbon practically completely to carbon dioxide, and so utilizing in this way the whole calorific value of the fuel inside the smelting furnace. But the supposed means which should have realized this intention did not materialize.

Today it is aimed at in the two-stage process, by the combination of a rotary furnace and a low-shaft furnace. In this way it is also possible to utilize the right quality of heat. It is wrong to produce the heat necessary for the smelting process with high-grade fuel only ; for reactions going on at a low temperature level low-grade fuel is sufficient, and only in reactions going on at high temperature should high-grade materials, *e.g.*, coke, electric energy, be utilized.

Of course, I cannot prove, in spite of being convinced of the fact, whether these processes will work on a large scale or not. They are just being developed. But what I do know is that we will have to change the way in which we produce iron in the future ; the raw materials we will have to use will compel us to do so.

Mr. **M. W. Thring** wrote : Dr. Durrer has summed up the matter very accurately when he divides the use of oxygen in the steel industry into two very distinct classes, short-term and long-term. The long-term plans imply the complete application of the principles of thermodynamics to high-temperature heating and the use of the heat of each temperature for its most appropriate purpose. Certain of the long-term processes are of important application to the British steel industry, but only those in which it is clearly expected that electricity and power are

* This assumption is, at least, not quite right, as there is always a certain amount of indirect reduction in the low-shaft furnace. Perhaps there is no great difference in this respect between the high-shaft and the low-shaft furnace, for in the latter there is no nitrogen, and tests have shown that in diminishing the percentage of nitrogen in the gas the indirect reduction is greatly intensified.

provided from coal. The immediate problems for the British steel industry are the short-term applications of oxygen, and here oxygen can be considered in terms of overall fuel saving. Calculations along these lines indicate that the British steel industry should be very active in this field and should instal oxygen plants in steelworks without waiting for experimental results from other countries. Provided the oxygen is manufactured from heat or power which is part of the same process, the greater the price of fuel the more important it is to use oxygen, *i.e.*, not to waste fuel on the heating of useless nitrogen.

Mr. Mather's point that the use of oxygen in the Bessemer should enable intermediate iron to be used, was a very important one, and strengthens considerably the case for immediate trials on the application of oxygen to the basic Bessemer. Mr. Reber's curves for the effect of oxygen on the flame temperature, with and without dissociation, are a very valuable contribution to the subject, but I would emphasize that so far oxygen has been used for combustion in the open-hearth furnace, not to raise the flame temperature, but merely to enable more fuel to be burnt in the laboratory, *i.e.*, to shorten the flame. I was very glad that Mr. Robiette referred to Messrs. John Miles' experiments on oxygen-blown converters, since these represent one of the most important contributions to the subject.

As regards Dr. Tigerschiöld's reference to the liquid-slag gas producer, the difficulty is that the operation of liquid-slag appliances on a small scale always involves a very heavy flux addition, so that the use of oxygen in gas producers will probably have to await the design of a producer which is omnivorous as regards ash, *i.e.*, can handle ash in the intermediate state between fully liquid and powdery.

I think the keen discussion on these papers indicates clearly that experiments on the use of oxygen in the steel industry are of very great immediate importance.

Joint Discussion on the Papers—

HYDROGEN AND TRANSFORMATION CHARACTERISTICS IN STEEL*

by J. H. Andrew, H. Lee, H. K. Lloyd, and N. Stephenson

and—HYDROGEN IN STEEL MANUFACTURE†

by C. Sykes, H. H. Burton, and C. C. Gegg

Mr. **H. H. Burton** (English Steel Corporation) presented the paper by Professor J. H. Andrew, H. Lee, K. H. Lloyd and N. Stephenson, entitled "Hydrogen and Transformation Characteristics in Steel."

Dr. **C. Sykes**, F.R.S. (Brown-Firth Research Laboratories) presented the paper by himself, H. H. Burton and C. C. Gegg, entitled "Hydrogen in Steel Manufacture," and pointed out that on pages 174 and 175, Figs. 19 and 20 had been transposed; "Fig. 19" should be "Fig. 20," and *vice versa*.

The **President** (Dr. C. H. Desch, F.R.S.) said that the papers represented a very large amount of work undertaken by the Hair-Line Crack Sub-Committee. When the problem became important, the question of hydrogen was at once raised. There were some sceptics who were doubtful whether hydrogen played any part in the phenomenon at all, but he thought that the work had shown that, whilst other factors had to be taken into account, hydrogen was the most important.

He would like to pay tribute to the way in which the various British steel firms had co-operated in the research. It had involved a great deal of work in the laboratories and in the works, and often meant making ingots and forgings which it was known would have to be scrapped. Although the problem had not been completely cleared up, great progress had been made. At first sight it might seem that the solubility of so small an atom as hydrogen and its diffusion through a lattice would be simple, but it had proved to be exceedingly complex, and in the second paper there was considerable discussion of the physics of the process. So far as a practical solution was concerned, he thought that many steelmakers knew how to produce steel free from hair-line cracks provided they had plenty of time. It was always when pressure of work had been acute and forgings had to be prepared quickly that there had been most trouble with hair-line cracks.

Dr. **F. D. Richardson** (British Iron and Steel Research Association, London), dealing with the problem of diffusion referred to in the second paper, on pages 173 onwards, said he had been struck by the very low figure calculated for the temperature coefficient for the diffusion of hydrogen in α iron, a figure corresponding to 2 kg.cal. per gram atom as against the value of 12 kg.cal. calculated for γ iron at higher temperatures. Other metals did not show values below about 6, and other workers on iron at low temperatures had produced figures of the order of 9 and 10 kg.cal., though the methods employed

* *Journal of the Iron and Steel Institute*, 1947, June, pp. 208–253.

† *Ibid.*, 1947, June, pp. 155–180.

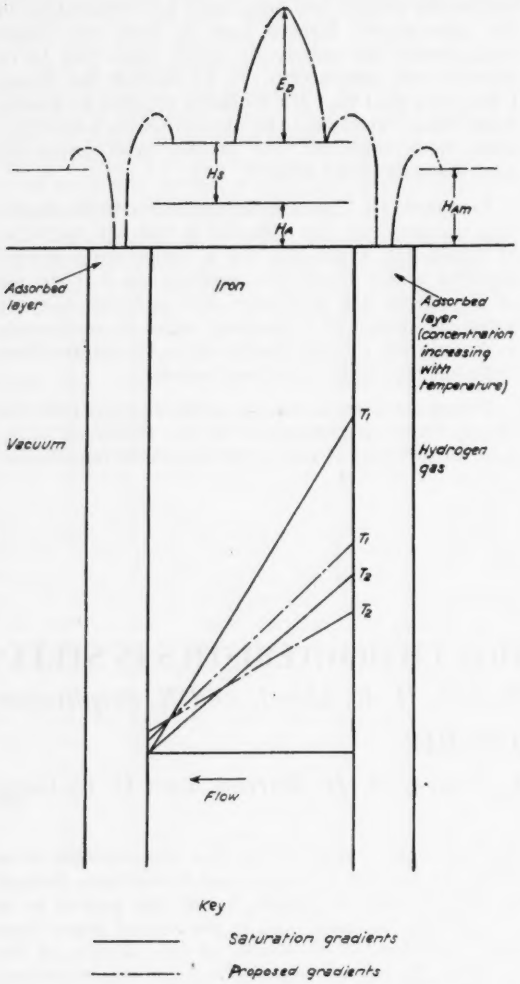


FIG. A—Energy changes for various steps

were not free from criticism. The value for the α iron is the more surprising since the heat of solution of hydrogen in both γ and α iron is the same and there is no great difference in the atomic spacing of the two forms.

It seemed to him that the assumption on which the coefficients had been obtained might not be valid at the lower temperatures and that the concentration gradient which actually occurred in the permeability determinations might be very much less than the assumed drop from saturation on one side to zero on the other. The reason for suggesting this was that the process by which the hydrogen got into the metal was certainly a complex one and involved quite a number of steps. The hydrogen molecule in the gas phase had to get into the metal, and the evidence was that it did this by first being adsorbed on the surface as atoms by activated adsorption, the heat of adsorption possibly being of the order of 5–10 kg.cal. per mol. Once the hydrogen atom was adsorbed it had to get into the lattice of the metal. The adsorption was exothermic and the solution process endothermic. The activation energy required for the hydrogen atom to go from the surface into the metal was therefore somewhat greater than the sum of these two heats. Having got into the iron, the hydrogen atom would, of course, move by the true diffusion process, involving the appropriate energy of activation. Finally it had to get out of the iron by an activated desorption process from the surface. His point was that it was obvious that there existed steps, involving considerable energies of activation and possibly low probability factors, both on the way in and on the way out from the metal, as illustrated in Fig. A.

Although these steps might be so fast as not to affect the permeability at the higher temperatures, they might exert an influence in the lower range. If so, the permeability would no longer be simply related to the solubility and the diffusivity, and any values for the diffusivity calculated on that assumption would be in error. If, for instance, the step from the adsorbed to the dissolved state were such as to affect the permeability, it could be shown that for reasonable values for the energy changes, the gradient in the plate would be less than the simple saturation gradient and would change much less with the temperature than the solubility itself. This was because the increase in the concentration in the adsorbed layer with decreasing temperatures, offset in large measure, the decrease in rate constant caused by the considerable energy of activation for the step from the adsorbed to the dissolved state. If such factors were taken into consideration in calculating the diffusivity from the permeability, one would obtain higher values in α iron, with higher values both for the constant factor (D_0) and the temperature coefficient, than those calculated in the paper; these would be more in line with other work. It was unfortunate that our knowledge of these factors was inadequate at present for any exact calculations to be made.

Finally, he drew attention to the fact that Smithells and Ransley's explanation, on pages 176–177, for the falling away from the straight lines in Fig. 21 had been shown by Barrer to lead to an endothermic instead of an exothermic adsorption. The true explanation might, he thought, again lie in changes in the rate-controlling processes and not simply in changes in the fraction of surface covered.

Dr. **M. L. Becker** (The British Iron and Steel Research Association, London) said it had now been shown that hydrogen was deleterious, though not the sole cause of hair-line cracking. He wondered why more attention was not paid to getting rid of the hydrogen entirely, as Dr. Sykes had suggested. It was in the liquid state that the hydrogen could be eliminated most easily, and he suggested that the hydrogen could be driven out by bubbling an inert gas through the liquid metal. Such a gas must clearly not be nitrogen, because that would be absorbed in

the steel, whilst gases containing oxygen, or carbon dioxide, would react with the steel too rapidly and disturb the equilibrium of the melt. He could only think, therefore, of carbon monoxide, which would only carburize the melt to a small extent, or a mixture of carbon monoxide and dioxide which could be controlled to exert no appreciable chemical reaction. It would be essential of course to ensure that the gas was free from traces of hydrocarbon and that it was thoroughly dried before use. He felt that if the experiment of bubbling such a gas through the melt had not been tried it ought to be. It might seem a little difficult from a practical point of view, but he was sure that that could be overcome.

CORRESPONDENCE

Dr. **N. J. Petch** (Cavendish Laboratory, Cambridge University) wrote : I should like to comment on these papers in the light of some work of mine, which is completed but not yet published. This work has been concerned with the possible means whereby hydrogen can have a detrimental influence on steel.

Professor Andrew and his co-workers in their present paper consider that the stress due to the accumulation of molecular hydrogen in internal cavities is of major importance in hair-line cracking. Such pressures form the basis of the most widely accepted theory of hydrogen embrittlement, it being supposed that the embrittlement arises from the strain-hardening and triaxial stress distribution introduced by the cavity-pressure system. In my work, I have shown that this theory is unsatisfactory and have replaced it by one which supposes that the hydrogen present structurally lowers the brittle strength. This term is used to mean the stress required for intercrystalline or cleavage-plane fracture. Such a theory is in agreement with the interpretation of room-temperature tensile tests on the Ludwik-Davidenkov theory of fracture, and also with direct measurements of the brittle strength at the temperature of liquid nitrogen. The probable structural distribution of the hydrogen atoms in iron solid solution is such that an effect on the brittle strength is plausible.

Apart from being unable to account for hydrogen embrittlement, the actual existence of cavities containing high-pressure hydrogen in steels with the usual hydrogen contents that produce hair-line cracks, can be shown to be quite uncertain. Thus the possibility of such pressure contributing to the stress producing hair-line cracking is quite uncertain. This is also true of the high pressures of methane which Professor Andrew and his co-workers consider may be of importance.

Hair-line cracking arises from the combination of the embrittlement of steel by hydrogen, and the various stresses that are set up during cooling. Measurements which I have made of the macroscopic internal stresses due to differential contraction and due to movement of the transformation from the outside inwards in 6-in. dia. bars of the 3¼%-nickel–chromium steel S.11, indicate that these stresses are too small to account for hair-line cracking. I have therefore reached the conclusion that lack of uniformity in structure due to micro-segregation plays an important part in producing the conditions that lead to cracking. Lack of uniformity in the transformation will produce local stresses. Also, tensile tests which I have carried out on hydrogen-containing steels in various conditions indicate that the lower the transformation temperature becomes in a particular locality the more brittle will be the material there in the presence of hydrogen ; consequently the less will be the fracture strain, and the fracture stress may also be considerably lowered. This conclusion about the importance in hair-line cracking of the inhomogeneity of structure is in agreement with that reached in the paper of Sykes, Burton, and Gegg.

The importance of localized conditions could explain the incubation period which may occur in hair-line cracking. It could be that the stress and strain conditions for fracture are only established in the special localities after the transformation has continued there for some time at room temperature. Such an explanation of the incubation period is different from that which has been advanced by Andrew and his co-workers.

AUTHORS' REPLIES

Professor **J. H. Andrew,** in reply wrote : We wish to thank those who have contributed to the discussion.

Dr. Petch has mentioned his work on hydrogen embrittlement and has, very briefly, indicated his view on the subject. We shall be looking forward to reading his paper and in particular, to studying his methods and results from which his theory of hydrogen embrittlement in steel will be formulated. From what Dr. Petch has stated in his contribution, we gather that his main point is the assumption that it is the atomic hydrogen which remains in solution and is responsible for the brittle behaviour of the steel. It may well be said that the presence of foreign atoms, particularly if they can be assumed to occupy certain positions in the iron lattice, would normally be expected to influence the resistance to flow or the shear strength of the material. Dr. Petch might have very conveniently taken this view in order to bring the effect of hydrogen upon the ductility of steel into line with the general principle of brittle fracture in testing materials as first laid down by Ludwik.

Without knowing the experimental results which support his statement, it seems to us that the fundamental difference between our view and that of Dr. Petch, is that the pivot of the whole matter is hinged upon two controversial points, *viz.*, the validity of the contention that iron containing atomic hydrogen in solid solution could necessarily be identified in itself as a brittle structure, and the question of the *actual* existence of internal cavities in steel in which the molecular hydrogen can be stored under high pressures.

In speaking of a brittle structure as related to the probable distribution of hydrogen atoms in solution in iron, Dr. Petch might have drawn certain analogies between hydrogen and carbon dissolved in iron. Quite possibly he might have had in mind the brittle nature of martensite although he has not made this point clear. Owing to the considerably smaller size, hydrogen atoms when present in the iron lattice are not in a 'frozen' state as carbon is, and that they are relatively *mobile* even at room temperature is borne out by the fact that hydrogen escapes freely from iron specimens. Unless Dr. Petch can prove to the contrary we fail to see that, to use Dr. Petch's own words, "the probable structural distribution of the hydrogen atoms in iron solid-solution is such that an effect on brittle strength is plausible."

Even so, we have not *entirely* overlooked the possibility of hydrogen having some effect upon the stress/strain relationship in steel. In the course of our investigations we have endeavoured to measure the elongation of a series of tensile test-pieces at the maximum load. The test-pieces were initially treated to a given structure with varying *average* hydrogen contents and the results compared with the corresponding control specimens. The tests were carried out at room temperature at approximately the same speed. It was found that the variations observed were not large and they were certainly inconsistent with the *average* hydrogen content of the specimens. It would seem that the effect of hydrogen upon the ductility of the steel was marked only after 'necking.' In our opinion this observation is in good agreement with the fact that hydrogen affects the reduction of area more than the total elongation as shown in our paper as well as that of Sykes, Burton, and Gegg.

In so far as we are aware, the measurement of the fracture strength of a ductile material is faced with many difficulties because of the 'necking' preceding the fracture. The well-known straight-line relationship between stress and strain by means of the log./log. plot has been found to break down beyond the 'necking' point and no corrections could be applied with confidence and certainty. These remarks, however, apply to plastic metals and alloys in general. In dealing with a steel contaminated with hydrogen especially, according to Dr. Petch, if this hydrogen is supposed to lower the brittle strength of the material, we shall be most interested to know the way in which Dr. Petch has tackled the problem and arrived at his conclusions. If the hydrogen content of a specimen was very high, it might be that a 'real' brittle fracture could be obtained, *i.e.*, the specimen breaks without 'necking.' In such a case, the measurement of the fracture strength of the material would be a relatively simple matter. We have not yet had the experience of obtaining a 'real' brittle fracture in hydrogen-soaked and isothermally transformed steels, it may be that the hydrogen content of our specimens was too low, being of the order of 3·5 c.c./100 g. We did not think it wise to carry out experiments on specimens treated to give martensitic structures for obvious reasons. On the other hand, we have some results in hand (not yet reported), showing that with the hydrogen being introduced into a specimen electrolytically, certain steels initially treated to a soft condition but with certain structures were rendered extremely brittle and at the same time the tensile strength of such a specimen was very much lowered. On subsequent tempering at 100° C. for a long time, it was found that the hydrogen content could be reduced to a low value, but the specimen remained brittle and its tensile strength was also not fully recovered. Our view is that the carbides in these specimens are unstable, so that when hydrogen is introduced into the specimen, any attack upon the carbides will leave a permanent weakness presumably at the carbide–metal inter-phase boundaries. Such a weakness cannot be expected to be recovered by low-temperature tempering. A similar inference may be derived from results obtained on a vanadium steel for which hydrogen was introduced by soaking. Unlike *CR5*, specimens of this steel isothermally transformed at a higher temperature (600° C.) possessed a greater tensile strength than similar test-pieces which were treated at a lower temperature (400° C.), but the embrittlement effect due to hydrogen was found to be less for the former in spite of the higher tensile strength. Also, we have sectioned many tensile specimens after testing for failure. It was observed that in some of the hydrogen-containing test-pieces there was a zone of many small internal cracks, near but distinctly away from the fracture. No such cracks have been found in hydrogen-free test-pieces nor in other parts of the hydrogen-containing specimen far away from the fracture. This may not be difficult to explain if we assume that hydrogen pressures in internal cavities and the applied stresses are additive, but we should like to know whether this and the many other facts given above could possibly be fitted in with Dr. Petch's new theory.

Another very important fact which confronts any hydrogen embrittlement theory is that hydrogen has no effect upon the mechanical properties of high-alloy austenitic steels, as shown in our paper as well as borne out by the experience of Sykes, Burton, and Gegg. In view of the considerably greater solubility, a larger amount of hydrogen would be expected to remain in solid solution at room temperature in austenitic than in ferritic steels. Moreover, owing to the co-existence of carbon and hydrogen atoms in the same lattice, the movement or the mobility of such hydrogen atoms might, quite conceivably, be hampered with the result that some of them can be imagined to be 'locked up' in the lattice or 'trapped' in solution. This may increase the solid solubility still further. Indeed, it is a common experience that austenitic steels usually retain a very large amount of hydrogen. With due regard to the slower rate of hydrogen diffusion in austenite, our impression is that, once retained, hydrogen does not appear to escape from austenitic steels at all at room temperature. Taking the hydrogen content and the non-embrittling effect in austenite steels into account, it seems this fact is quite contrary to Dr. Petch's idea that hydrogen in iron solid solution gives rise to a brittle structure. It may of course be said that the lattice structure is of fundamental importance; for example, carbon in solid solution in alpha iron such as martensite, gives rise to brittleness whereas

austenite containing carbon remains very ductile. To this argument we may draw attention to the fact that carbon in austenite or ferrite increases the strength of the structure but hydrogen does not.

Referring to Dr. Petch's second point on which he remarked, "the actual existence of cavities containing high-pressure hydrogen in steel with the usual hydrogen contents that produce hair-line cracks, can be shown to be quite uncertain." We shall be glad to know the way he shows it. In the meantime, we wish to draw Dr. Petch's attention to a more recent paper[1] in which we have given our conception of internal cavities containing high-pressure hydrogen and certain experimental results which appear to fit in with this idea. We shall be pleased to have his comments. Although we do not quite know what would be the amount which Dr. Petch has referred to as the "usual" hydrogen content which gives rise to hair-line cracks in steel, we take it that this may be something of the order of 5–6 c.c./100 g. On the basis of Luckemeyer-Hasse and Schenck's calculation based on Sievert's solubility data, the general impression is that the "usual" hydrogen content which has been found necessary for hair-line crack formation in practice is actually *higher* than what appears to be sufficient from theoretical calculations. Here again, Dr. Petch may have good reason to show that these calculations are incorrect.

We are fully aware of the importance of local or other stresses in steel. In fact we have repeatedly expressed the view that residual stresses play an important part in determining the distribution of hair-line cracks. As already pointed out, it is reasonable to assume that if conditions are favourable, local stresses and internal pressures due to hydrogen are additive. We have shown also, that the uniformity of structure is important in determining the extent of embrittlement caused by hydrogen.

Finally, Dr. Petch remarked vaguely upon certain transformations. He maintains that this transformation could continue for some time at room temperature in special localities and claims that this will explain the incubation period. We assume that Dr. Petch refers to the gamma–alpha transformation. In the absence of any experimental proof we may refrain from prolonged comments but we hope that such a proof will be forthcoming. If it can be shown that under all circumstances where hair-line cracks in steel occur there is some retained austenite and the subsequent decomposition of this austenite gives rise to internal cracks in the specimen, we shall only be too pleased to accept the explanation. As a matter of fact, we held a similar view in earlier days[2] but we had to give it up because of many reasons. We consider that under certain industrial conditions where prolonged low-temperature soaking and slow cooling are the usual practice, it is very unlikely that austenite is retained to room temperature in normal low-alloy steels. If it is assumed that local segregation could result in high-alloy concentrations which may lead to retained austenite in these regions then there is no reason to suppose that this austenite should decompose with time at room temperature under otherwise unchanged conditions. On the contrary, we have shown in an earlier paper[3] as well as in this one that, using a high carbon ball-bearing steel, hydrogen-soaked and water-quenched specimens showed no cracks. Such specimens could be expected to contain a certain amount of retained austenite if not more than similar specimens of other types of low-alloy steels which were found to give many internal cracks.

References

1. J. H. ANDREW and H. LEE : "Symposium on Internal Stresses in Metals and Alloys," p. 265, 1947. Institute of Metals.
2. J. H. ANDREW, A. K. BOSE, H. LEE, and A. G. QUARRELL : *Journal of the Iron and Steel Institute*, 1942, No. II, p. 203.
3. J. H. ANDREW, H. LEE, A. K. MALLIK, and A. G. QUARRELL : *Ibid.*, 1946, No. I, p. 67.

Mr. **H. H. Burton** wrote : In reply to the comments of Dr. Becker which were given in the brief discussion which was possible at the meeting, I would like to point out that there is no positive evidence that bubbling an inert gas through the liquid steel before casting the ingot would reduce the hydrogen content to a sufficiently low level to obviate the formation of hairline cracks. Furthermore, to carry out this operation would be an exceedingly difficult matter, and even if means were found there would still remain the problem of the hydrogen picked up from the ladle lining—in cases where ladles have been freshly patched—and from the ingot feeder head, which is known in some cases to be a source of hydrogen.

The written contribution from Dr. Petch is particularly interesting and it is gratifying to hear that Dr. Petch's work has led him to the conclusion that hairline cracks are most probably due to a combination of embrittlement by hydrogen and various stresses set up during cooling. The practical evidence in support of this view is very substantial and the publication of the results of Dr. Petch's own researches will be awaited with great interest.

Discussion on the Paper—
OBSERVATIONS ON CONDUCTING AND EVALUATING CREEP TESTS*
By W. Siegfried

Mr. **W. Siegfried** presented his paper.

Mr. **D. A. Oliver** (William Jessop and Sons, Ltd., Sheffield) said that the paper was of very great value to metallurgists in Great Britain, because during the war their work was regarded as confidential, publication was prohibited, and general discussion was impossible. Moreover, they had always been very impressed by the thorough work which had been done in Switzerland for many years. It was known throughout the world that the Swiss were the first to industrialize the gas turbine, and therefore, presumably, the first to run into all the problems in question.

The British approach to the whole subject was fundamentally different from the approach of the author. They did not know much about it a few years ago, but they did know that it was complicated, and they found so much contradictory information associated with the simplest possible parallel tensile creep specimen or parallel hot tensile test that they had not got to the stage when they would be so bold as to advocate the widespread adoption of the notched test-piece. On the other hand, they had not been unmindful of the problems of notches and blade-root fixings.

He thought that the author would probably admit that the photograph he had shown (Fig. 3) where the teeth had bent and the blade had pulled out, could equally have been of a ductile blade material at high temperature in a disc material of considerable strength at the same temperature. On the other hand, the author rightly pointed out that if one had an unsuitable material and its hot ductility was limited, and especially if the geometrical design of the blade root was wrong, one obtained precisely the kind of fracture which he showed, but there were so many variables in that particular type of test that one would feel that one would be very much better off either by keeping the test severely simple and going to the final engineering structure for the answer, or else simplifying even the notch problem to a more elementary version of the actual design that was under contemplation.

In Great Britain, when they had been concerned with the effect of notches in blade roots they had had recourse to photo-elastic studies which, of course, only gave a detailed solution for the elastic case. They had regarded that information as giving guidance and not a final answer, and when it came to the question of studying the actual blade-root fixing they felt that it was misleading to deal with only one blade dummy and one root fixing. They found that it was necessary to consider at least two blade-root fixings on either side of a single blade under test. It would be very interesting to know whether the author himself had found that necessary, because there could be important sideways reactions the moment the blade tried to pull out, and if one had not simulated the reaction conditions of reality, one could readily get a false result; either the fixing would be too strong because there was a mass of solid metal on either side of it, or, if the test-piece had been made too narrow, there would be insufficient sideways support and an unduly pessimistic result would be obtained.

The general method of analysis using the **S** curves was something on which as far as he was concerned he must withhold judgment. They intended to look into it carefully. It was to them a somewhat new method of approach, and unfortunately the interval between receiving the paper and the present opportunity of discussing it had been insufficient to allow any kind of deep analysis to be undertaken. He would conclude, therefore, by saying once again how much British metallurgists appreciated the author's entirely fresh approach to an important problem.

Mr. **W. E. Bardgett** (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) remarked that the study of the effects of stress concentrations on materials operating under various conditions of stress in service at normal temperatures was a relatively simple matter, yet a considerable amount of research had been devoted to it. At elevated temperatures, as pointed out by the author, the problem was of course much more complicated, and it was obvious that the subject must receive a good deal more attention than had been given to it in the past. It was known that moving parts at normal temperatures usually failed at a position of stress concentration, and efforts were directed to minimizing the stress by design or else by treatment of the material in such a way as to overcome the effects of the stress concentration, such as by nitriding, shot-peening and so on.

For high-temperature service, stress concentrations were, of course, a major factor under static as well as dynamic conditions. It was clear, therefore, that the field in which the author had been working was one which warranted the closest study, and the work which he described could not be too highly praised. It was of interest here to refer to investigations by a subcommittee of the British Electrical and Allied Industries Research Association on the failure of 0·5% molybdenum steel. This occurred in the form of steam pipes, and led to a recommendation which was of particular interest in its bearing on this subject. The recommendation was that it was highly important that pipes should have smooth and undamaged surfaces, and that grooves, fissures, indentations, hammer marks, and other irregularities which would cause stress concentrations should be prevented or

* *Journal of the Iron and Steel Institute*, 1947, June, pp. 189–207.

removed. The expressed hope of the sub-committee was that their inquiry would lead to the formulation of some suitable form of test which would enable material which was susceptible to cracking to be excluded from service. The work of that sub-committee was continuing, and no doubt due regard would be paid to the work of the present author.

The evaluation of notch sensitivity on the basis of the true stress-contraction curves and notched specimens was undoubtedly a matter for serious consideration in evaluating materials for high-temperature service, but it would be interesting to know how far the author considered that the evaluation on this basis might be simplified. Did the author consider it possible to determine the relative notch sensitivity using one selected notch, or was it necessary to make the evaluation on a number of notches, and precisely how was the evaluation of the notch sensitivity made in relation to the **S** curve ?

The tests illustrated in Figs. 2, 3, and 4 were extremely interesting and, in view of the complexity of the problem of failure under complicated stress systems at elevated temperatures, they indicated that it would be useful to consider when possible the testing of materials under conditions simulating, as far as possible, the service conditions as regards design. Probably in no field of engineering was co-operation between designer and steel producer more necessary than it was in the high temperature field, from a design point of view on account of the necessity of having the right type of data, and from the producer's point of view in knowing precisely what type of information was required, on account of the time-consuming nature of his tests. It was obviously desirable to obtain just the precise information which was wanted for design purposes, and agreement between the producer and user was very necessary in that respect.

The author made the interesting suggestion of identifying the most important physical property which could be measured readily in a suitable way, and which was directly related to the change in condition affecting high-temperature behaviour. This was to be applied as a check on the reliability of extrapolation of sustained-load curves. This indirect method would require a very complete understanding of the high-temperature characteristics to be applicable with sufficient certainty, and it was doubtful whether any shortened form of test would be of direct assistance in guaranteeing safety in machines, though it might well serve as a guide in the selection of those materials for further investigation. The great value of such a method of examination, if it were proved completely reliable, must be fully appreciated, and it was worthy of very serious consideration.

Dr. **L. Jenicek** (Czechoslovak Mining and Metallurgical Institute, Ostrava) congratulated the author and emphasized the importance of the paper, which showed the significance of the design and form of the test-pieces used at high temperatures, a question which was sometimes neglected. It was due to the influence of Professor Roš and his school, that in Switzerland these questions were investigated in all branches of engineering, and that facilitated the work of metallurgists who were concerned with this problem. On the other hand, it proved the necessity of restricting the design and form of the simple test bar on which the elongation was determined. For ordinary creep tests they used a number of test bars 2 in. and 4 in. long. At the General Electric Company at Schenectady he saw test bars 10 in. and 20 in. long used for creep tests, and in Sweden he saw test-bars of which the two halves of the test length were of different diameters, so that it was possible to determine the creep under two specific loads. He thought that it would be reasonable to restrict that number, especially if only the creep of the material was studied and not the influence of design.

The classical creep test which gave good information about the conditions, for example, in the boiler was not sufficient for the solution of the problem of the gas turbine, and there it was necessary to use the combined fatigue test and corrosion test, as was proved in papers to be discussed later. He thought that it was very appropriate that the Swiss should initiate international collaboration in this field, and the present paper proved their competence to do so.

The present paper and those which were to follow also proved that the physical metallurgist could attain very important results with relatively simple and cheap means in comparison with the process metallurgist. In that connection, one had only to recall the discussion about oxygen which took place the previous day. The situation of Dr. Durrer and of all those who were interested in that problem would be much easier if they had at their disposal much cheaper apparatus than they possessed ; in the present case the investigation, in spite of its effect on the gas turbine, was very much cheaper.

CORRESPONDENCE

Dr. **C. Sykes** (F.R.S.) wrote : The author has drawn attention to the difficulties associated with the prediction of the creep properties of heat-resisting steels from short-term data, and has drawn particular attention to the behaviour of such steels in the notched condition—a very complicated but nevertheless very important aspect of the problem.

Dealing first with creep tests in the unnotched state, the author refers to tests on an unstabilized austenitic steel of which the log/log plot of strength *versus* endurance is not a straight line, and shows that this steel becomes strongly ferro-magnetic after prolonged treatment at 650° C.

There are two metallurgical transformations which may occur in the complex austenitic steels if the analysis is not properly balanced, (*a*) breakdown of austenite, and (*b*) deposition of sigma phase. Both transformations can usually be detected after prolonged treatment at elevated temperatures in the *absence* of stress ; the writer mentions this because it is often convenient to test for stability independently and thus reserve creep machines, which are always in short supply, for the determination of actual design data. Such transformations affect the magnetic properties in the 18/8 steels, as the author has indicated, they also materially alter room-temperature

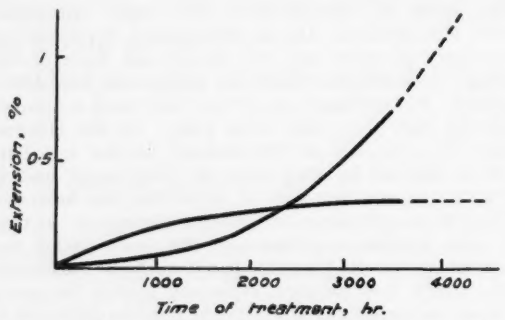


FIG. A—Creep curves of a stabilized steel after different treatments

mechanical properties, *i.e.*, izod, elongation, and also electrical resistivity.

It does not follow that an austenitic steel which gives a log/log plot similar to Fig. 5 undergoes a metallurgical transformation. Creep curves of widely differing shape may be obtained on stabilized steels, where presumably only long-term precipitation is taking place without the appearance of any new phase in obvious amounts.

Curve *A* (Fig. A), *e.g.*, gives a continuously increasing creep rate, but up to 1000 hr. the curve might readily be taken as a straight line. Curve *B*, up to 1000 hr., is practically straight; at 3000 hr. the creep rate is practically zero. This latter curve is very similar to curves obtained on ferritic steels used in steam-turbine practice, but is obtained on certain austenitic steels. The shape of the curves changes with the duration of the test, consequently it is possible to obtain curves similar to Fig. 5 with materials which are usually defined as stable. (Material *A* was non-magnetic, and austenitic with unimpaired room-temperature properties when tested after a creep test lasting 7000 hr.)

On the question of the notch effect, the author's results were very difficut to interpret. The writer had never been able to grasp Kuntze's basic ideas even when applied to material in the elastic condition, consequently their extension to the plastic state with an effective notch radius which is indeterminate appears very speculative. This criticism of the theoretical treatment is not intended to detract from the importance of the tests from the practical aspect.

He would like to ask the author one or two questions regarding the failure of the notched specimens. Did the cracks first form on the surface of the notch and go inwards, or did they start from the centre and work outwards? Where would he expect the cracks to form first on the basis of Kuntze's theory, *i.e.*, inside or outside?

Presumably the reductions of area were measured on the broken test-pieces after fracture; it would be useful to know what reduction of area occurred before any cracking appeared. This point is emphasized since under service conditions, fatigue stresses may be important and then presumably, any crack will be extended by fatigue irrespective of the creep loading.

As an example of the complexity of high-temperature work and the effect of notches, the following experience would interest the author. Recently in testing an experimental steel, the life of the notched test-piece came out to be some 5–10 times that of the unnotched specimen in the steady-load rupture test. The fatigue properties of the material, however, were found to behave quite normally, both notched and unnotched.

The experimental work carried out by the author is laborious and the production of the test-pieces and their measurement after fracture needs great care and patience. Whilst it is disappointing that no clear-cut conclusions have been forthcoming regarding the effect of notches as a result of the author's investigation, nevertheless it is to be hoped that he will continue his work. It is only by the accumulation of such experimental data that the practical significance of notches in high-temperature design is likely to be advanced.

Mr. Siegfried made no verbal reply to the discussion at the Meeting and, at the date of going to press, a written reply to Dr. Sykes' contribution had not been received. Additional correspondence on the papers presented at the Meeting in Switzerland will be published in a future issue of the *Journal*.

Joint Discussion on—

THE SECOND HATFIELD MEMORIAL LECTURE—STEELS FOR USE AT ELEVATED TEMPERATURES,* *by C. Sykes, F.R.S.*

and the Papers—

REQUIREMENTS OF STEEL FOR GAS TURBINES†

by H. R. Zschokke and K. H. Niehus

and—

THE SCALING BEHAVIOUR OF HIGH-STRENGTH HEAT-RESISTING STEELS IN AIR AND COMBUSTION GASES‡

by W. Stauffer and H. Kleiber

Dr. **C. Sykes**, F.R.S., presented the Second Hatfield Memorial Lecture ; Mr. **K. H. Niehus** presented the paper by himself and H. R. Zschokke, and Mr. **W. Stauffer** presented the paper by himself and H. Kleiber.

Mr. **C. G. Conway** (The Mond Nickel Co., Ltd., London) said that the papers contained a wealth of detail on the properties of high-temperature materials. These data, when carefully considered, might help the engineer in his difficult task of designing heat engines, but without due consideration his task might well be all the more difficult. At the present time, the engineer wished to make use of materials which could operate for long periods of time at temperatures above 600° C. In order to do that it was necessary, as the authors had pointed out, to make as full a use as possible of the data to be provided by laboratory experiments. At the same time, the engineer must not allow himself to be misguided by data which were not strictly applicable. While laboratory experiments could give indications of future behaviour, there could be no short cut ; only by the results of service trials over long periods, coupled with full details of running conditions on materials chosen on the basis of reasonable and well-planned laboratory experiments, could the answer be found.

Here he wished to differ radically from the statement made by Zschokke and Niehus ; there was not, in his opinion, any theoretical basis for extrapolation of creep behaviour into the future. Since the maximum economic period of creep test was between 10,000 and 15,000 hr., the designer of, for example, an auxiliary turbine must base his design, and had done so in certain notable instances, on a component life of 20,000 hr., though he might have 100,000 hr. in mind for the life of the installation. On that basis, the designer was unlikely to run into serious difficulty. When one was forced to make an extrapolation, the most conservative figures possible should be used. The double logarithmic method adopted in two of the papers presented that morning could lead to grievous error, and should be treated with great reserve.

It would be well at this time to consider the sources of error in creep testing, and examine their effect on the attitude to be adopted on the results obtained. Taking first the temperature of test, in any industrial laboratory this was a most difficult condition to maintain. He would quote as an example a verbal report on one industrial country in Europe, in which a check on the measurement of the temperature in the 650° C. region showed differences as great as 15° C. between various industrial laboratories. To anyone with just a nodding acquaintance with the art of high-temperature testing, the effect of such a difference did not need to be described.

A major difficulty arose here, since the successful application of laboratory data to service depended on the determination of blade and disc temperatures, apart from the other components of the turbine, where the problem was more complex than in the laboratory. In any one laboratory the mean temperature difference between any two given creep tests could be placed at about 2°–3° C. on an average, due to temperature fluctuations over the course of the test, differences in the thermocouple calibration, and differences in the gradient along the specimen. Such differences could give an error of about 30% in the time to reach any given elongation. That could be readily seen by plotting the data on a temperature basis.

Other errors were of importance ; the non-uniformity of cross-section of the test-piece even from the best workshops, and the difficulty of maintaining true axial loading, could lead to additional errors of about the same magnitude as those caused by temperature. It was thus necessary, in considering the course of a plot of stress against time, to map out the probable

* *Journal of the Iron and Steel Institute*, 1947, July, pp. 321–369.

† *Ibid.*, 1947, June, pp. 271–283.

‡ *Ibid.*, 1947, June, pp. 181–188.

scatter band, preferably on a linear stress against a logarithmic time basis.

Zschokke and Niehus were right to draw attention to the possibilities of structural change, which might have disastrous effects in a turbine installation. The evidence of change and deterioration must, however, be sought in the material itself, and not in data plotted on an artificial basis.

In criticizing the double logarithmic plot, he would say that in his experience it did not give straight lines, and one would not expect it to do so. He would recommend that if on stress/log.-time plotted data there was definite evidence of progressive declination from the straight line outside the scatter band and towards the abscissa, then the quality of the material used in those tests should be examined exhaustively at the end of the test. That did not preclude examining the materials in any case.

To some extent, his remarks on the validity of laboratory experiments applied to the paper by Stauffer and Kleiber. The conclusions, as the authors pointed out, were somewhat at variance with the general picture which one had in one's mind, of the behaviour of the steels in question under such conditions. The apparent inhibition of attack by the presence of high sulphur had, he believed, been noted before in a catalytic plant under alternating oxidizing and carburizing conditions, and might be due to the prevention of carburization.

He would repeat that there could be no short cut in this development; they must be willing to buy at least some of their experience.

Mr. **D. A. Oliver** (William Jessop and Sons, Ltd., Sheffield) said that there was one point on which he differed slightly from Dr. Sykes, who had just given a summary of his excellent Hatfield Memorial Lecture. He was rather more optimistic than Dr. Sykes about

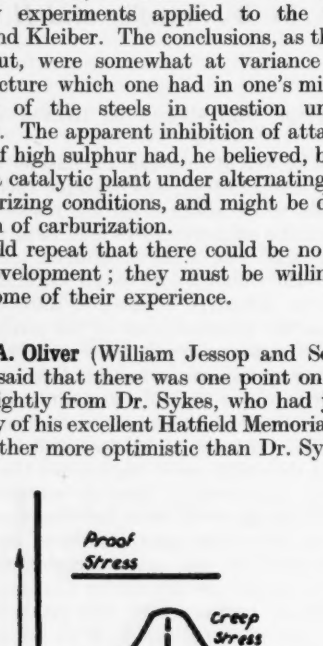


FIG. A—Definition of warm-working temperature for a high creep strength austenitic steel

the solution of some of the difficulties relative to the higher-alloyed steels for operation at the higher temperatures. In some recent work which they had undertaken they had, to their great satisfaction, found that the alloy segregation in some of the very complicated highly alloyed steels was surprisingly small as measured by taking an ingot, sectioning it, drilling it at different points, and considering the gradient in alloy concentration.

In dealing with very large rotor forgings it was wise not to take them up to the highest solution temperatures, and in cooling, which was often air cooling, the position again was not so bad, because if the centre cooled more slowly and was virtually tempered after solution treatment, the properties which one observed in consequence of that were that the maximum stress and the proof stresses increased, whereas the creep resistance decreased slightly. At the periphery of the rotor the full solution treatment had been obtained, and substantially a quench had been imposed. When one worked out the consequences of that, one found that it happened to go the right way, because one got the highest creep resistance in the hottest zones

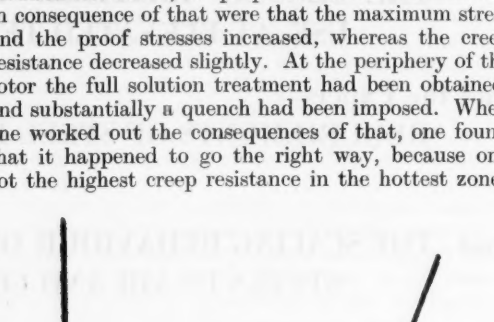


FIG. B—Curves showing different types of scaling behaviour

and one had only to sacrifice a little creep resistance where the lower temperature conditions were experienced.

There were two points to which he would like to refer in the excellent paper by Zschokke and Niehus. In Fig. 5, where the effect of the cold work was recorded, one distinguished between two broad effects. By forging the materials in question at temperatures anywhere in the range 400°–700° C. there was obtained in all cases an increase in the proof stress which was quite important when one considered speeding-up under cold-running conditions. What they had found was that the creep properties went through a peak so that if they were plotting to a base of temperature they found that they could achieve the same low-temperature (15° C.) proof stress at different forging temperatures. One could get either good or poor creep properties, and they had coined the phrase ' warm-work ' for additional forging at that temperature where they increased the creep properties to a maximum as well as increased the proof properties to what was required (*see* Fig. A). There was a final variable, residual ductility, and that had to be decided quite arbitrarily in the light of the application.

They were very much indebted to the authors for pointing out the tendency to serious σ-phase formation which was recorded in Fig. 8 and which had been shown by the very beautiful photomicrographs. That information was not generally known in Great Britain

until the authors tackled it, and some recent work with which he had been concerned corroborated it perfectly. There seemed to be a limit round about 22–23% of chromium in the steel under consideration in which one did run into some degree of σ-phase formation.

Finally, with regard to the paper by Stauffer and Kleiber, the subject which they had studied helped to balance very well the series of papers. As a matter of interest, they had found that a vertical furnace with convection was, with regard to oxidation in air, a very useful way of getting rapid results, and curves were obtained of the type shown in the accompanying sketch. They tended to find a temperature above which, in rapidly oxidizing conditions, the scaling tended to follow the form of curve *A*, when the scale which was formed rapidly fell off and more was formed. Where a very adherent scale was produced it tended to follow the form of curve *B*, the adherent scale becoming partly protective. They found it very useful to compare steels which had different starting points along the temperature scale, such as 900°, 1000°, 1100°, and 1200° C., and in that way it seemed possible, within ± 50° C., to say that if one worked below that temperature one was substantially scale-free, whereas if one worked above it one rapidly ran into a large amount of serious scaling.

Mr. **J. T. Mackenzie** (United States Steel Export Co.) said he had just seen the data presented regarding the sigma phase, but in the experiments, in their steel laboratories at Pittsburgh, on stainless steel they found that the sigma phase could occur in austenitic-type steels with as low as 18% of chromium. It was generally found in the higher molybdenum-bearing austenitic steels, but there had been other cases of steels containing 18 or 19% of chromium with nickel—the 18/8 type of steel—which showed sigma formation following exposure to high temperatures, and the evidence indicated that it had formed from the ferrite phase which was present due to the unbalanced nature of these alloys. On the other hand, experiments at the Carnegie Institute of Technology had shown that the sigma phase could form directly from a pure austenitic phase, so that it was not possible to be absolutely sure that there was any lower limit in the chromium content necessary for sigma formation as long as an alloy contained other ferrite formers or sigma formers of the nature of molybdenum. This should be a word of caution for those working with high-temperature steels, because molybdenum is a familiar alloying element, and with high molybdenum types there seemed a definite tendency for the formation of sigma phase, even with very low chromium contents.

Dr. **T. P. Hoar** (Cambridge University) said he had listened with very great interest to the two papers on the high-temperature resistance of the modified chromium–nickel steels. He agreed with the previous speaker that caution was necessary in connection with the formation of the σ phase in such steels, particularly as the modifications that improved scaling resistance and creep resistance at high temperatures were additions of molybdenum and silicon. The previous speaker had emphasized the influence of molybdenum in leading to σ formation even in steels of low or comparatively low chromium content. He would like to add that silicon was also a σ former; in steel containing as little as 17% of chromium, with additions of about 3% of molybdenum and 2·5% of silicon, σ formation could take place very readily in the range referred to. It was unfortunate that the σ embrittlement occurred, because there seemed to be evidence, perhaps rather tentative, that so far as scaling was concerned the formation of σ was no disadvantage, and might even be slightly advantageous.

Mr. **W. E. Bardgett** (The United Steel Companies, Ltd., Stocksbridge, near Sheffield) remarked that in Dr. Sykes's very interesting paper there was one point which was referred to very briefly, but which he thought was exceedingly important. On page 11 a statement was made that as a matter of interest he also carried out accurate measurements of the variation in length of unstressed specimens but exposed at 650° C., and showed that contractions of up to 0·1% could occur, depending on the prior treatment. They themselves, Mr. Bardgett said, had confirmed that changes in dimensions of the same order were obtained in certain high-alloy steels, and it would be of interest if Dr. Sykes would say how far he took into consideration such dimensional changes in the unstressed condition when considering material which was being tested under creep conditions.

The work carried out by Zschokke and Niehus on the effect of cold work on creep was of particular interest, but the results given referred to relatively short periods of test. It would be interesting to know to what extent the results were modified by longer periods of testing. It did not follow that even a small amount of cold or warm work would improve the creep resistance. They themselves had carried out tests on a steel of a somewhat similar type to No. 5 on page 200 of the paper, and in tests at 650° C. the material was warm-worked 3%, and this gave rise to a decrease in creep resistance. The time for 0·1% of plastic deformation with a stress of 20 tons/sq. in. was greater than 300 hr. when in the solution-treated condition and only about 3 hr. when warm-worked at 700° or 800° C., although the temperature at which precipitation disappeared was higher than 800° C. The effect of that amount of cold work, however, was sufficient to double the proof stress which, of course, was quite important.

While cold or warm work might improve the creep resistance, it was possible that, as was pointed out in the paper, over-ageing might be unduly accelerated. Whilst that expedient had been resorted to in materials for aircraft, where the true and total effect of the warm work could be evaluated, it was of questionable value when materials were subjected to service during periods beyond the normal range of testing. In either case the aim should be to provide materials which would give the desired properties without warm working, since the latter was open to the objection that it was not readily controlled and that the same optimum degree of work might not be possible for the

components as a whole, and that a suitable method of selection of specimens might be difficult.

It was stated in the paper that there was no relationship whatever between creep limit and the hardness at 20° C. He would agree with that, and would further state that there was no relationship between the creep resistance and the increase in hardness during the period of the creep test or with the maximum precipitation hardening of the material.

The authors had dealt with the importance of high fatigue strength and resistance to corrosion. It was known that corrosion could affect the fatigue strength very considerably at normal temperatures with quite a mild corrosive agent. It would appear that the evaluation of corrosion fatigue at high temperatures might be a matter for serious consideration, and it would be interesting to know how far it would actually be a problem in the gas turbine.

Dealing with combustion chambers, since these had only to carry their own weight it would be useful to have an assessment of the permissible degree of embrittlement. Obviously one would say that the notched-bar impact test was too severe unless one considered perhaps quite a small value of impact, say of the order of 5–10 ft.lb., but the impact test would not then be a very suitable way of discriminating, and it might be that a bend test would give a better assessment of the material with regard to the embrittlement which could be tolerated in service.

On page 280, Zschokke and Niehus referred to a short-time test as a basis of design. It would be interesting if they would state what was the longest period adopted.

The work carried out by Stauffer and Kleiber was very valuable. He himself had had in mind the point which Mr. Oliver had so well brought out. He thought that it was not possible to expect a consistent differentiation between steels and scaling tests when the degree of scaling was quite small, and one would rather group them into the range of temperature where the material did not show a marked increase in scaling. It would be interesting if the authors could include some photomicrographs to show the form of attack on the materials in the presence of different amounts of sulphur.

There was a further point of considerable importance in the scaling test, and that was the time factor. The type of scale obtained could, as Mr. Oliver had already mentioned, differ, and where it was of the adherent type it reduced further attack, and in a certain period steel *A* might have a greater scale resistance than steel *B*, but after a longer time the relative resistance of the two steels might change. It was very important to make an assessment not for one time but over a period of time, in order to see how the trend of scale resistance went.

Sir **William Griffiths** (The Mond Nickel Company, Limited, London) said he wished to take advantage of the opportunity provided by the discussion of Dr. Sykes's paper, which was the Second Hatfield Memorial Lecture, to pay a tribute to the contribution which the late Dr. Hatfield made to the subject of high-temperature alloys, particularly those for use at temperatures above 600° C.

Dr. Sykes had described what had been done in Dr. Hatfield's own laboratory and the part which alloys developed under the direction of Dr. Hatfield had played in allowing Group Captain Whittle to produce his first workable engine. This early work of Dr. Hatfield not only did this, but provided a great stimulus to others subsequently studying high-temperature materials.

It had been his own good fortune and that of his organization, Sir William said, to have become involved in this question just before the outbreak of the recent war, and when he had received the initial request from the Air Ministry to commence research on high-temperature materials the target which was to be aimed at, and of course to be exceeded if possible, was that which had already been set up by Dr. Hatfield. As some present no doubt knew, the alloys which resulted from these researches, and which were in fact principally used for blade materials in Great Britain at the present time, could not in any way be called steels, but he was free to confess that they may not have been developed at all had not Dr. Hatfield set a high mark for others to aim at.

He had also been fortunate in having paid a number of visits to the United States during the war at the request of the then Ministry of Aircraft Production, and he had early become acquainted with the work which was going on there. He had not himself had much experience of war-time developments on the Continent, but from what he had learnt of the position on both sides of the Atlantic, it was clear that Dr. Hatfield had been amongst the most successful of the pioneers in this field of study.

It was fitting that those who came after Dr. Hatfield should pay a tribute to what he had done.

While speaking, Sir William said he wished to emphasize one other point, which was that if advances were to be made in the application of high-temperature alloys to engineering, it would be necessary to take risks, sometimes even expensive ones. There was a natural tendency to hesitate to put materials into service before they had been exhaustively studied in the laboratory and it was clear from the discussion that morning that we still had much to learn regarding the significance of the laboratory tests which so far we were able to employ. He would be the last to decry the importance of laboratory investigation and testing, but when one considered the time involved in any creep test or long-time fatigue test, and the many variables involved in connection with the successful production of any satisfactory material, it was clear that if one waited for absolute certainty and definiteness from laboratory tests before making actual service trials, the development of the gas turbine and all its possibilities might have to wait a long time. It was certainly doubtful whether, as yet, we knew how the indications of creep and other curves obtained in the laboratory were reflected in service behaviour, and until we had service experience to relate to laboratory test figures this difficulty would continue.

At the same time he would like to remind engineers that, whilst he was wholly in favour of initiating as promptly as possible the laboratory tests of long duration which undoubtedly would have to be carried

out, the subject was still young and was continually and rapidly developing. Thus, even before a long-time test perhaps lasting several months had been completed, improvements in composition or production procedure might well have taken place in regard to the alloy under test, and the results obtained therefore might not be representative of the material available at the conclusion of the test. In other words, the material tested might well be already out of date.

This did not mean, of course, that they should not go ahead with long-time tests, but it did call for a recognition by all concerned of the actual stage in which we now were in the development of these relatively novel materials.

Finally, in spite of what he had just said, he considered that there was one direction in which engineers should certainly satisfy themselves before proceeding far with any new material. There should be reasonable expectation that the material could be regularly provided on a works scale in the form required and with the properties exhibited in the laboratory test. In his experience progress in this field had been not a little hampered by an occasional forgetfulness of the truism, particularly marked in the case of new developments, that the obtaining of high test figures on even several laboratory-made specimens is not quite the same thing as the regular provision of these figures in industrially made parts produced in quantity.

Dr. **C. Sykes,** F.R.S., wrote : We have compared the results obtained by Stauffer and Kleiber with similar work carried out in our own laboratories. Their conclusions are in good agreement with our own experimental results although the authors have used gaseous mixtures which contained less free oxygen than those employed in our tests.

Our experience would suggest that the scatter observed in some of the tests might at any rate in part be attributable to variable gas flow around the specimens, of which 18 were treated at once, rather than to material variation. We would appreciate the authors' comments on this.

On the question of the nickel content at which sulphur attack becomes important, we have carried out tests on various austenitic steels ; *viz.*, 18/8, 25/20, etc., a 65/15/20 Ni–Fe–Cr alloy, and an 80/13 Ni–Cr alloy in an atmosphere with 50% of excess air. At 1000° C. no increase of scaling was observed on the addition of 0·5% of sulphur (by volume) on any of the steels or on the 65/15/20 alloy. At 1100° C. a definite increase of scaling was noted on the 80/13 alloy on the introduction of sulphur.

There is a suggestion from the authors' results, Figs. 11–15, of some increased scaling in the highest sulphur-containing atmosphere for *all* steels in the neighbourhood of 900° C. This may be a genuine effect in atmospheres containing no free oxygen or in reducing atmospheres. It would be useful if the authors could elaborate this point, since it may be of considerable practical importance in connection with combustion chambers, etc., where, due to imperfect mixing, local pockets occur in which reducing conditions exist.

AUTHORS' REPLIES

Dr. **C. Sykes** wrote : Mr. Oliver's view is that the author has rather over-emphasized the difficulties associated with the manufacture of large austenitic forgings, but adds that it is not wise to subject such forgings to the highest solution temperature, *i.e.*, to those commonly used for bar. Under such circumstances, whilst segregation effects are not so important, the optimum creep properties cannot be obtained. On the question of quenching and mass effect Mr. Oliver is prepared to tolerate some deterioration in properties as one passes from the outside to the centre of the forging. In certain designs where there is an appropriate temperature gradient the author agrees that the deterioration is not important, but there are designs, however, in which the difference in temperature from that at the outside to that of the inside is negligible and where the highest temperature is at the centre of the forging. Under these conditions uniformity of properties is desirable.

In reply to Mr. Bardgett, the author has nothing further to add regarding the change in dimensions which occur when unstressed specimens are exposed at elevated temperatures. No doubt during the ordinary creep tests this effect occurs but is masked by the elongation produced by the stress.

The graceful tribute paid by Sir William Griffiths to the late Dr. Hatfield is much appreciated. There is no doubt that Dr. Hatfield's contribution to the development of steels for high-temperature service is an outstanding one.

Mr. **K. H. Niehus**, in reply, agreed with Mr. Conway that the utmost care must be taken to prevent any errors in the testing apparatus coming into the judgment of the behaviour of the steels, and also that care must be taken to see that the temperature measurement was accurate, although in that case it was necessary to bear in mind that the temperature was not absolutely constant in the machine, so that if a steel was very sensitive to a temperature change of a few degrees only, or even of 10 to 20°, it would not be of much use in an actual machine. For these tests the temperature was checked daily and held constant within $\pm$ 3° C. during a test period of 6 weeks. He also agreed that an extrapolation from a few hundred or a few thousand hours to 100,000 hours was very unsatisfactory, but he did not think that the extrapolation in a double logarithmic scale was any worse than an extrapolation in a linear-stress/log.-time scale. On the contrary, deviations from the straight line of the log./log. diagram could be better than from the curve of a linear/log. diagram. When transferring the data which Mr. Conway had originally plotted in a linear-stress/log.-time diagram to a log./log. system one found the distinct break in the stress/time line which could not be observed before. They pointed out in the paper that for certain steels they had actual experience for long running periods, and they had to balance that against the short-time tests. For high temperatures and new alloys that experience was not yet available, and there they would have to take a

step into the unknown, and whether any extrapolation would help or not could be decided only by experience. What Mr. Mackenzie had said about the sigma phase was very interesting, although unpleasant. Personally, he was inclined to believe from recent tests and experience, that the sigma phase would occur even at 18% of chromium. This had been confirmed by tests made since writing the paper.

Dr. Hoar's views about the addition of molybdenum or silicon and its effect on the

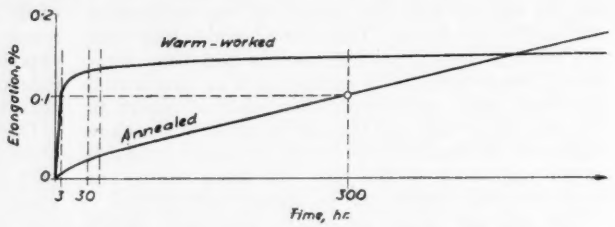


FIG. C—Comparison of creep curves of a material in the warm-worked and annealed conditions

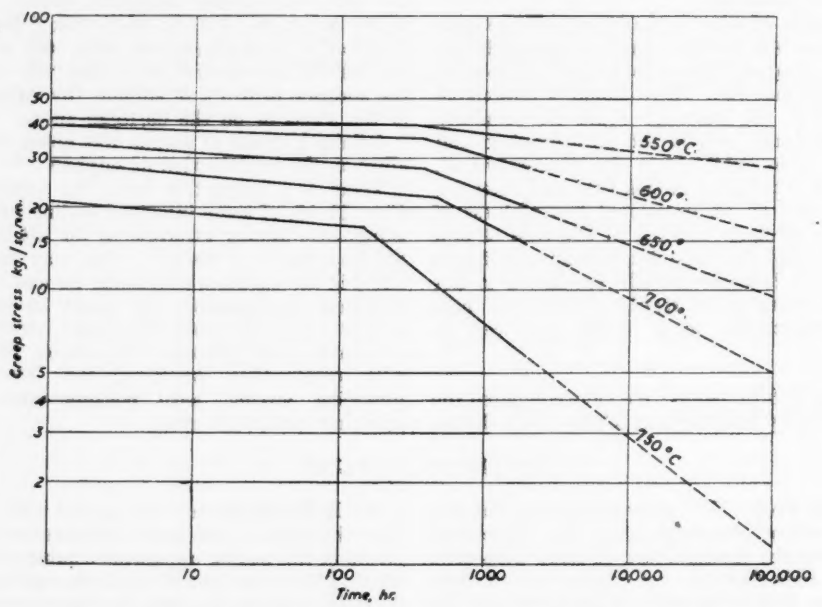


FIG. D—Behaviour of a cold-worked steel during a 2000-hr. creep test

sigma phase corresponded with their own experience.

Mr. Bardgett had wanted to know the period of the tests referred to (on page 280 of the June *Journal*). They were 2-day creep tests, and the creep rate was measured from the 35th to the 45th hours of the test.

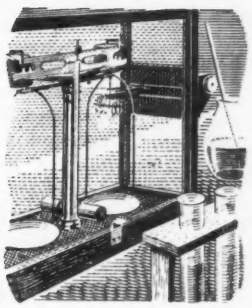
The behaviour of cold-worked steel in long-time tests of 2000 hr. was shown in Fig. D. Annealed, this steel had an elastic limit of 25 kg./sq. mm. at 20° C.

Before comparing results they must have agreed upon defining a creep limit. It was possible that in the tests mentioned by Dr. Bardgett the warm-worked test-piece had had a considerable initial creep elongation immediately after loading, followed by a stage of small creep rate, whereas the annealed bar had behaved more steadily, showing a continuous medium creep rate. The result could have been that after 1000 hr. the total creep of the first bar would have been less than that of the second, in spite of the fact that it had reached the 0·1% creep limit sooner, as shown in Fig. C. Also, when applying a short-time creep limit based on a limited creep rate in the 30th hour of the test, the first test-piece would have been considered the better one.

The question of what degree of embrittlement was still permissible in steels for combustion chambers was easy to answer. Embrittlement was permissible as long as the lining of the chamber would stand up to the work without cracking. They could not give actual figures, because very little was known about the stresses in the combustion chamber due to thermal expansion. For testing the embrittlement of straight chromium steels they used a simple bend test and not an impact test, in agreement with Dr. Bardgett. They required a bending angle of 180°, and the tests were, of course, made after heating the test specimens at 700° C. for 200 hr. to allow for possible sigma-phase formation. The question of corrosion-fatigue strength must be investigated, because very little was known about it at high temperatures. Concerning the corrosion problem he could say that in their experience there was no corrosion of turbine blades in combustion gases at 600° C., provided the chromium content was not less than 18%.

B. I. S. R. A.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION



Spectrographic Analysis of Low-Alloy Steel*

A STATISTICAL EXAMINATION OF SOURCES OF ERROR

By H. T. Shirley, B.Sc., A.R.C.S.,† E. Elliott, Assoc.Met.,† and Joyce Meeds†

SYNOPSIS

The main study has been carried out with a single sample having the following composition :

C, %	Si, %	Mn, %	Cr, %	Ni, %	Mo, %
0·30	0·25	0·58	0·77	2·75	0·50

Readings were taken for silicon, manganese, chromium, nickel, and molybdenum from 30 spectrograms from each of thirty-one plates. These plates were taken under conditions involving excitation by means of normal Hilger equipment consisting of a 15,000-V. transformer, a 0·005-μF. condenser, and no added inductance.

The results of some 60,000 readings from upwards of 9000 individual lines have been treated statistically to obtain estimates of variability contributions from the three main sources : (1) Excitation response, (2) small-scale plate variability, (3) microphotometry. The greatest variability in excitation response occurred when using two pencil electrodes cut from the steel sample. Better results were obtained with either silver or graphite auxiliary electrodes. The standard deviation for excitation variability then corresponded to 1·5% of the chromium content, when using a chromium (II) line with an iron (I) line ; but when using a new line-pair, composed of two singly ionized lines, this was reduced to 0·9%. Small-scale plate variability was studied by measurement of two independent 0·5-mm. lengths from each line, and Ilford Thin-film Half-tone plates were outstandingly good in this connection, with a standard deviation corresponding to about 0·7% of the chromium content. The microphotometry error was of the order of 1% of the chromium content. Total variability from these three sources, therefore, corresponded to a standard deviation of the order of 2% for the chromium (II)/iron (I) line-pair. By using the chromium (II)/iron/(II) line-pair, this was reduced to 1·9%, the considerable improvement in sparking response being offset to some extent by lower sensitivity of this line-pair.

Results published by Vincent and Sawyer indicate a substantially lower overall variability, a figure of 0·7% of the content being quoted for 1% of chromium. It is shown that, in comparison with the results from the present investigation for the new chromium–iron line-pair, this lower overall variability is in great part due to a very small photometry error in the American work, the figure quoted corresponding, under the present authors' conditions, to a standard deviation of only 0·25 mm. in reading an individual line with a 50-cm. full-scale deflection.

* Paper MG/DD/6/46 submitted by the Spectrographic Analysis Sub-Committee of the Methods of Analysis Committee of the British Iron and Steel Research Association (Metallurgy (General) Division), received 18th July, 1947. The views expressed are the authors' and are not necessarily endorsed by the Sub-Committee as a body.

† Brown-Firth Research Laboratories, Sheffield.

XUM

Introduction

From time to time claims have been made for relatively high accuracy in the spectrographic analysis of steel and iron. For example, in a paper on " Precision in Spectrographic Analysis," Vincent and Sawyer* described work with material from a single bar of 1% chromium steel, indicating a standard deviation in repetition work of only 0·7% of the chromium content. Again, in the 1941 Symposium on Spectrographic Analysis,† Sawyer stated that analysis of silicon at the Ford factory was carried out with a standard deviation of 1·2% of the 2–3% present, while for most metallic elements standard deviations were not more than 1% of the amount present.

The results of a considerable number of analyses of low-alloy steels carried out by the authors under conditions involving inclusion of mixed qualities on single plates, have indicated a lower order of accuracy. Typical results were given in a paper‡ to the Iron and Steel Institute in 1943. In order to obtain a more satisfactory comparison with the American figures and to permit study of the contribution of various sources of error, it was decided to carry out work with a single quality of steel.

Preliminary Work

A preliminary study was made with samples from nine casts of nickel–chromium–molybdenum steel of the general composition 2½–3% of nickel, 0·75% of chromium, and 0·5% of molybdenum, with 0·3% of carbon, 0·25% of silicon, and 0·6% of manganese.

Two of the nine samples were exposed twice on each plate for use as standards, while the remaining seven samples were taken four times each to give 14 determinations per plate for each element, determinations being made, according to the authors' standard practice, from the means of duplicate spectrograms. Twelve plates were taken in this way and details of procedure and lines read are given in Appendix I.

Modifications in development were studied, development being carried out by three procedures. The plates used were of Kodak *B*20 type and were developed in Kodak *D*19*b* developer at 18° C. for 4 min. as follows :

(1) Four plates were treated in plain developer for 15 sec. with initial agitation, followed by development for 3¾ min. without agitation.

(2) Similar treatment to (1) was given to a further series of four plates, but with an addition of 0·5% of a wetting agent, Teepol, made to the developer.

(3) For the remaining four plates, plain developer was used, but vigorous agitation was carried on throughout development.

The reading of these twelve plates and calculation of log " intensity " ratios from plate-calibration curves was carried out as described previously by the authors (*loc. cit.*). Variability was expressed in terms of standard deviations from the mean of the spectrographic results for the whole series. The values obtained were of the order of 5% of the content for silicon, 4% for manganese, 3% for chromium, and 2·5% for nickel and molybdenum. No significant difference was found between individual plates, or between the three methods of development.

Main Investigation

At this stage it was decided that a more detailed study of the magnitude of the contributions by various sources of error was essential in order to discover, in the first place, what were the major causes of the higher errors, and in the second place, to provide a means of quantitatively checking the effect of modifications in technique and materials. Consideration was given to the published work of Vincent and Sawyer (*loc. cit.*), and a rather similar basic procedure adopted. The treatment, however, has been considerably different in detail, and further consideration will be given to this aspect when comparing the results.

It was desired to break down the total variability into three parts, the reading error, the contribution from small-scale variability and minor defects on the plates, and that introduced by variability in excitation response.

For this purpose a series of 31 plates was used with 34 spectrograms on each, all obtained with a single sample of nickel–chromium–molybdenum steel.

The sample chosen for the work was one of the nickel–chromium–molybdenum steel samples used in the preliminary studies.* The taking conditions were essentially as described in Appendix I with two exceptions. Thus in certain cases the auxiliary electrode was varied from silver to graphite or steel pencils machined from the actual sample block, while development was in most cases by the modified procedure described in Appendix II.

Throughout the work, log " intensity " ratios were employed as in normal analytical practice. In this way a direct estimate of the effect of the various errors on actual analyses has been possible, and the procedure was more closely

* *Journal of the Optical Society of America*, 1942, vol. 32, No. 11, pp. 686–692.

† " Spectrochemical Analysis in the Iron and Steel Industries." American Association for the Advancement of Science, Dec. 1941.

‡ H. T. Shirley and E. Elliott, *Journal of the Iron and Steel Institute*, 1943, No. I, pp. 299P–337P.

* The chemical analysis of this sample was as follows : 0·30% C, 0·25% Si, 0·58% Mn, 0·77% Cr, 2·75% Ni, and 0·50% Mo.

related to practice than one in which the results were based on photometer readings of single lines.

The line-pairs used for the main study were those listed in Appendix I, being those employed in the earlier work described by the authors (*loc. cit.*).

As in the preliminary work, the log " intensity " ratios used were based on photometer readings corrected for plate response. This correction is made by conversion of the readings according to a curve giving the relationship between photometer readings and the logarithms of exposure times to a mercury-vapour light-source. This source of illumination has been a Mercra mercury-vapour lamp set up in a similar position to the normal spark gap, exposures from 5 to 100 sec. covering the density range required from the various plates. While this method of calibration is theoretically open to criticism, log-time not being strictly interchangeable with log " intensity," the procedure has been found in practice to provide satisfactory correction and has been applied to routine analysis over several years. The required log " intensity " ratios are obtained by subtraction between the log-time values corresponding to the photometer readings for the iron and element lines respectively. The authors' normal practice is to use the log " intensity " ratio for the comparison iron line over the element line, and all log-ratios in the present paper have been calculated in this way.

From each plate the first 30 readable line-pairs were used. Thus in the event of accidental damage or a large defect preventing satisfactory reading

TABLE I—*Distribution of* σ_{T9} *Deviations*

Plate*	Element	σ_{T9}	Deviation Limits ±	Number Outside Limits	
				Gaussian	Actual
*RXB*263 Kodak *B*20	Chromium	0·0083	0·0035	40	45
			0·0065	26	21
			0·0095	16	14
			0·0125	8	11
			0·0155	4	6
			0·0185	1·2	1
*RXB*305 Kodak *B*5	Chromium	0·0065	0·0025	42	43
			0·0045	29	29
			0·0065	19	22
			0·0095	9	12
			0·0125	3	4
			0·0155	0·9	1
*RXB*328 Ilford Thin-film Half-tone	Silicon	0·0041	0·0015	43	41
			0·0025	33	28
			0·0045	16	14
			0·0065	7	6
			0·0085	2	3
			0·0105	0·7	1
*RXB*328 Ilford Thin-film Half-tone	Chromium	0·0040	0·0015	42	33
			0·0025	32	25
			0·0045	16	17
			0·0065	6	5
			0·0085	2	3
			0·0105	0·5	1
*RXB*328 Ilford Thin-film Half-tone	Nickel	0·0025	0·0005	50	49
			0·0015	33	34
			0·0025	19	19
			0·0035	10	8
			0·0045	4	5
			0·0055	2	3
			0·0065	0·6	0

* All these plates were taken with a graphite auxiliary electrode and with 15-sec. pre-spark.

of lines, it was possible to omit up to four spectrograms. This margin proved sufficient for all the plates used in this investigation.

The photometry was carried out on two independent 0·5-mm. lengths of line from the 1·7 mm. available in each case. Normally these two readings were carried out on portions of lines 0·1 mm. from ends, known as the top and bottom readings respectively. Where a spot or other mark or defect was visible to the reader, sufficient shift from these positions has been permitted to clear the defective portion, but in the absence of such visible defects, no shift has been made, however poor the check between top and bottom readings.

In order to reduce the reading errors, each line-pair was read three times by different operators. Standard deviations, apart from reading errors, were then calculated from the means of these three readings. Where the three individual readings gave log-ratios differing by more than 0·010, check readings were made. Also, where the mean ratios for top and bottom readings differed by more than 0·010, inspection was made for the presence of any defect or damage justifying a change in reading position. In this way reading errors were minimized and incidental complicating factors avoided, as far as possible, in relation to the other deviations studied.

Assessment of variability has been made in terms of "standard deviations," assuming sufficiently random variability in the 30 spectrograms from any given plate. Table I illustrates the essential correctness of this assumption, giving figures for σ_{T9} for five cases where nine repeat readings were carried out in connection with the determination of residual reading errors. This standard deviation, σ_{T9}, was based on the variations between the mean log-ratios for nine readings of individual spectrograms and the mean for the whole plate for the particular element in question, two values, corresponding to readings of independent 0·5-mm. lengths, being obtained from each line-pair. The figures show a very reasonable approximation to a Gaussian distribution.

A complete schedule of the standard deviations used is given in Appendix III. Before considering the figures obtained for these, however, it is necessary to give some more detailed consideration to their derivation and significance.

From the 900 log-ratios deduced from the readings of each plate, three main standard deviations were calculated as follows :

(1) σ_{TC} including the variability introduced by sparking response and plate response. It is calculated from

$$\sigma_T = \sqrt{\frac{\Sigma d_T^2}{59}}$$

where d_T represents the difference between the individual log-ratios and the mean for the whole series of 60. Correction for residual reading error is made according to :

$$\sigma_{TC} = \sqrt{\sigma_T^2 - \sigma_{RT}^2}$$

σ_{RT} being deduced as described later.

(2) σ_{PC} covering the variability introduced by local variation in plate response. This was determined from the difference between the top and bottom readings for individual spectrograms. These gave :

$$\sigma_P = \sqrt{\frac{\Sigma d_P^2}{2 \times 30}}$$

which was corrected to σ_{PC} by means of σ_{RP} for residual reading errors, as in the case of σ_{TC}.

(3) σ_{SC} representing the variability from the sparking response of the sample, including contributions from the sample and from the excitation source. It was calculated as :

$$\sigma_{SC} = \sqrt{\sigma_{TC}^2 - \sigma_{PC}^2}$$

Besides these main deviations, the following were calculated :

σ_{TMC} corresponding to σ_{TC} but based on the means of top and bottom readings in each case. This is of practical interest since such readings of two independent segments where only single spectrograms are used for each determination can be used to provide a check against plate variability and reading errors.

σ_{PMC} calculated as :

$$\sqrt{\sigma_{TMC}^2 - \sigma_{SC}^2}$$

This should be equal to $\sigma_{PC}/\sqrt{2}$ and should correspond to the value of σ_{PC} for readings of 1·0-mm. segments in place of the 0·5-mm. lengths used in the present work.

σ_R calculated from the differences between the individual readings of 0·5-mm. line lengths and the means of three such readings according to :

$$\sqrt{\frac{\Sigma d_R^2}{2 \times 60}}$$

The use of 2 in the denominator is, of course, based on the use of $(n - 1)$ in place of n, since the comparison is made with a derived mean. As discussed later, it is not considered that this will be strictly accurate in the case of means of only three readings, but it gives a check of the general level of reading errors.

An estimate was desired of the magnitude of σ_{RT}, σ_{RP}, and σ_{RTM}, the corrections required for residual reading errors in the corresponding standard deviations σ_T, σ_P, and σ_{TM}, based on the means of three readings. To obtain this, nine readings were made of selected line-pairs from three plates. An Ilford Thin-film Half-tone plate, *RXB*328, was read in this way for silicon, chromium, and nickel, to obtain figures at three density levels, and the results were further checked by reading chromium on a Kodak *B*20 and a Kodak *B*5 plate, *RXB*263 and 305 respectively. In all cases the nine readings were grouped in three sets of three, each worked out normally for the

TABLE II—*Comparison of* σ_{RT}^2 *Estimated by Various Methods for Plate* RXB*328*

Element	Method of Calculation		
	$\sigma_{RT}^2 = \frac{\Sigma d_3^2}{2 \times 60}$	$\sigma_{RT}^2 = \frac{\Sigma d_3^2}{3 \times 60}$	$\sigma_{RT}^2 = \frac{\Sigma d^2}{8 \times 60 \times 3}$
Silicon	584	389	340
Chromium	462	308	304
Nickel	552	368	365
Mean	533	355	336

means of three readings. These three sets of figures, representing the means of three readings, were themselves meaned, and their differences ($d3$) from this mean of nine were used to estimate σ_{RT}. A similar procedure, working with means of the top and bottom readings for each pair of lines was used to calculate σ_{RTM}. Finally, σ_{RP} was based on the variation in differences between top and bottom readings for means of three readings and the corresponding figure from the means of nine readings.

In all these cases the (n-1) denominator rule for a derived mean involves division by $\frac{2}{3}n$. This is a very considerable correction for inaccuracy of the mean, and the frequency with which σ_{PC} and σ_{PMC} became negative in the case of small values of σ_P and σ_{PM} indicated that the residual reading error corrections were, in fact, too high. It may be noted that a value for σ_{RT}^2 can also be obtained from the sum of the squares of the differences between individual readings and the means of nine readings, with a denominator of $3 \times \frac{2}{9}n$. Comparison of the values obtained for three elements from *RXB*328 in this way, as against the use of n for sets of three readings, is made in Table II.

These results support the idea that the denominator in the case of three results should be taken as nearer to n than to (n-1). On the other hand, it will be seen later that a similar comparison in

TABLE III—*Residual Reading Error Corrections for* σ_T, σ_{TM}, *and* σ_P

Plate:	*RXB*328 (Ilford Thin-Film Half-Tone)			*RXB*305 (Kodak *B5*)	*RXB*263 (Kodak *B20*)	Mean
Line-Pair:	Si 2881·6 Fe 2885·9	Cr 3408·8 Fe 3404·4	Ni 3515·1 Fe 3513·8	Cr 3408·8 Fe 3404·4	Cr 3408·6 Fe 3404·4	
Average Photometer Readings (clear glass 50 cm.):	Si 31 Fe 20	Cr 20 Fe 24	Ni 7 Fe 8	Cr 20 Fe 24	Cr 16 cm. Fe 20 cm.	
σ_{RT}	0·0022	0·0020	0·0021	0·0020	0·0022	0·0021
σ_{RTM}	0·0018	0·0015	0·0018	0·0017	0·0018	0·0017
σ_{RP}	0·0023	0·0024	0·0024	0·0022	0·0023	0·0023

TABLE IV—*Illustration of Effect of Corrections for Residual Reading Errors*

Standard Deviation*	*RXB*328 Ilford Thin-Film Half-Tone			*RXB*305 Kodak *B5*	*RXB*263 Kodak *B20*	Means
	Silicon	Chromium	Nickel	Chromium	Chromium	
σ_T	0·0045	0·0043	0·0043	0·0067	0·0082	0·0058
σ_{TC}	0·0039	0·0038	0·0038	0·0064	0·0080	0·0055
σ_{T9}	0·0041	0·0040	0·0025	0·0065	0·0083	0·0055
σ_P	0·0029	0·0031	0·0029	0·0039	0·0053	0·0037
σ_{PC}	0·0017	0·0020	0·0018	0·0032	0·0048	0·0029
σ_{P9}	0·0023	0·0027	0·0025	0·0036	0·0051	0·0034
σ_{SC}	0·0036	0·0032	0·0016	0·0056	0·0064	0·0044
σ_{S9}	0·0034	0·0030	0·0004	0·0055	0·0065	0·0043
σ_{TM}	0·0040	0·0038	0·0023	0·0063	0·0075	0·0051
σ_{TMC}	0·0037	0·0033	0·0016	0·0061	0·0073	0·0049
σ_{TM9}	0·0039	0·0035	0·0018	0·0061	0·0074	0·0050
σ_{PMC}	0·0009	0·0009	0·0002	0·0025	0·0035	0·0020
σ_{PM9}	0·0019	0·0019	0·0017	0·0027	0·0034	0·0024

* σ_T, σ_P, and σ_{TM} are the means for three sets each containing three readings and with no residual reading error correction. σ_{TC}, σ_{PC}, σ_{SC}, σ_{TMC}, and σ_{PMC} were similarly deduced, but corrected for residual reading error according to the values in Table III. σ_{T9}, σ_{P9}, σ_{S9}, σ_{TM9}, and σ_{PM9} were calculated from the means of all nine readings with no correction for residual reading errors.

regard to the full reading error, σ_{R1}, actually gave slightly higher " $(n\text{-}1)$ denominator " figures for groups of three than in the case of groups of nine. The use of a value somewhere between the extremes of n and $(n\text{-}1)$ must be assumed, and in the absence of more definite indications, the mean of these two values has been used in the present work. While this is obviously an approximation, it is probably fairly close to the optimum value, and results for the various residual reading errors calculated in this way are given in Table III. The agreement between the values for the various plates and elements is so close that the means from this Table have been used throughout the work with the main series of 31 plates.

To indicate the effect of these reading error corrections on the magnitude of the various standard deviations, Table IV gives for these plates and line-pairs, corresponding values for the means of nine readings worked normally in three sets of three, both with and without residual reading error correction as indicated in Table III. It also gives values calculated from the means of the nine readings with no correction for residual reading errors. It is seen that in general the order of differences is such that no serious misinterpretation is likely to arise from uncertainty as to the precise magnitude of the residual reading error corrections, particularly where comparison between plates in regard to a single deviation is required.

Before considering the main series of results, it is also of interest to examine the magnitude of the effect of avoiding small defects in the reading by offsetting from the normal reading positions,

TABLE V—*Effect of Minor Plate Defects* on Values for* σ_{PC} *and* σ_{SC}

Plate	Element	Number of Defects Involved			σ_{PC}		σ_{SC}	
		Light Spots	Dark Spots	Dark Lines	Without Offsetting	With Offsetting for Defects	Without Offsetting	With Offsetting for Defects
*RXB*307 Kodak *B*20	Si	0	6	5	0·0063	0·0036	0·0021	0·0025
	Mn	0	11	3	0·0049	0·0030	0·0082	0·0085
	Cr	0	30	0	0·0072	0·0043	0·0061	0·0054
	Ni	0	14	3	0·0034	0·0030	0·0046	0·0050
	Mo	0	24	2	0·0069	0·0048	0·0024	0·0045
	Mean	0	17	3−	0·0059	0·0038	0·0052	0·0055
*RXB*323 Kodak *B*10	Si	0	3	0	0·0031	0·0020	0·0034	0·0039
	Mn	1	1	0	0·0037	0·0030	0·0035	0·0033
	Cr	0	3	0	0·0033	0·0026	0·0043	0·0044
	Ni	1	0	0	0·0043	0·0030	0·0036	0·0036
	Mo	0	1	2	0·0019	0·0020	0·0029	0·0028
	Mean	0+	2−	0+	0·0036	0·0026	0·0036	0·0036
*RXB*329 Ilford Thin-film Half-tone	Si	0	2	2	0·0044	0·0028	0·0053	0·0046
	Mn	0	0	0	0·0007	0·0007	0·0039	0·0039
	Cr	1	1	1	0·0028	0·0028	0·0018	0·0019
	Ni	1	0	0	0·0041	0·0019	(−0·0014)	0·0013
	Mo	0	0	0	0·0017	0·0017	0·0029	0·0029
	Mean	0+	1−	1−	0·0028	0·0021	0·0033	0·0032
*RXB*343 Ilford Ordinary	Si	3	0	1	0·0078	0·0069	0·0071	0·0074
	Mn	3	2	0	0·0096	0·0057	0·0045	0·0055
	Cr	0	1	0	0·0076	0·0076	0·0061	0·0062
	Ni	2	3	0	0·0085	0·0071	0·0041	0·0033
	Mo	0	1	1	0·0092	0·0083	0·0037	0·0051
	Mean	2−	1+	0+	0·0086	0·0072	0·0053	0·0057

* Not including mechanical damage of plates necessitating occasional offset readings.

TABLE VI—*General Summary of Data for Main Series of Plates*

Plate No. (*RYB*)	Type	Auxiliary Electrode*	Source of Current	Time of Pre-spark, sec.†	Time of Exposure, sec.†	Development (*a*) Plain Dish (*b*) Kodak squeegee Method	σ_{SC} Si	Mn	Cr	Ni	Mo	σ_{PC} Si	Mn	Cr	Ni	Mo	Mean	σ_{PMC} Actual Mean	Calculated as $\sigma_{PC}\sqrt{2}$	σ_R Mean
248	Kodak *B20*	Graphite	Mains	0	20	*b*	0·0070	0·0066	0·0062	0·0034	0·0039	0·0040	0·0038	0·0043	0·0031	0·0035	0·0038	0·0025	0·0027	0·0026
250	,, ,,	,,	,,	0	20	*b*	0·0073	0·0064	0·0067	0·0035	0·0056	0·0040	0·0032	0·0039	0·0037	0·0039	0·0036	0·0024	0·0025	0·0028
251	,, ,,	Steel	,,	0	10	*b*	0·0092	0·0077	0·0092	0·0057	0·0044	0·0029	0·0045	0·0032	0·0033	0·0039	0·0036	0·0026	0·0025	0·0027
252	,, ,,	,,	,,	0	10	*b*	0·0073	0·0090	0·0116	0·0021	0·0040	0·0041	0·0047	0·0042	0·0032	0·0046	0·0042	0·0028	0·0030	0·0026
254	,, ,,	,,	,,	15	10	*b*	0·0052	0·0092	0·0092	0·0039	0·0026	0·0033	0·0046	0·0036	0·0039	0·0033	0·0039	0·0041	0·0029	0·0026
255	,, ,,	Graphite	,,	15	15	*b*	0·0070	0·0042	0·0053	0·0029	0·0028	0·0037	0·0044	0·0045	0·0032	0·0033	0·0038	0·0026	0·0027	0·0026
260	,, ,,	Steel	,,	15	10	*b*	0·0076	0·0106	0·0080	0·0036	0·0041	0·0038	0·0040	0·0045	0·0037	0·0038	0·0040	0·0029	0·0028	0·0027
263	,, ,,	Graphite	,,	15	15	*b*	0·0086	0·0055	0·0064	0·0035	0·0032	0·0042	0·0043	0·0048	0·0036	0·0035	0·0040	0·0029	0·0028	0·0026
287	,, ,,	,,	,,	15	15	*a*	0·0082	0·0026	0·0043	0·0034	0·0035	0·0034	0·0029	0·0030	0·0036	0·0030	0·0035	0·0025	0·0025	0·0033
292	,, ,,	,,	,,	15	15	*b*	0·0044	0·0059	0·0052	0·0012	0·0024	0·0049	0·0048	0·0038	0·0041	0·0030	0·0037	0·0027	0·0026	0·0031
303	,, ,,	Silver	,,	15	15	*b*	0·0045	0·0063	0·0053	0·0034	0·0025	0·0031	0·0035	0·0038	0·0035	0·0034	0·0037	0·0029	0·0028	0·0028
306	,, ,,	,,	,,	0	15	*b*	0·0086	0·0078	0·0070	0·0047	0·0015	0·0039	0·0035	0·0048	0·0030	0·0034	0·0037	0·0024	0·0026	0·0030
307	,, ,,	,,	,,	15	15	*b*	0·0025	0·0082	0·0054	0·0050	0·0045	0·0037	0·0030	0·0045	0·0030	0·0038	0·0038	0·0026	0·0027	0·0031
309	,, ,,	,,	,,	0	15	*b*	0·0074	0·0074	0·0051	0·0040	0·0029	0·0043	0·0031	0·0037	0·0034	0·0043	0·0038	0·0027	0·0027	0·0029
208	Eastman Kodak *N1*	Graphite	,,	15	20	*b*	0·0044	0·0051	0·0052	0·0029	0·0018	0·0018	0·0030	0·0029	0·0041	0·0028	0·0030	0·0020	0·0021	0·0027
271	,, ,,	,,	,,	15	15	*b*	0·0034	0·0075	0·0049	0·0047	0·0019	0·0027	0·0036	0·0037	0·0036	0·0032	0·0034	0·0022	0·0024	0·0027
282	,, ,,	,,	,,	15	15	*a*	0·0052	0·0036	0·0053	0·0035	0·0060	0·0032	0·0025	0·0043	0·0039	0·0033	0·0035	0·0023	0·0025	0·0027
280	Kodak *B5*	,,	,,	15	30	*b*	0·0047	0·0024	0·0044	0·0010	0·0038	0·0029	0·0025	0·0029	0·0020	0·0033	0·0028	0·0018	0·0020	0·0028
305	,, ,,	,,	,,	15	40	*b*	0·0047	0·0038	0·0056	0·0024	0·0023	0·0032	0·0017	0·0032	0·0039	0·0032	0·0031	0·0019	0·0022	0·0030
346	,, ,,	,,	Generator	15	50	*b*	0·0037	0·0049	0·0030	0·0030	0·0030	0·0038	0·0018	0·0038	0·0024	0·0021	0·0029	0·0017	0·0020	0·0033
347	,, ,,	,,	,,	15	30	*b*	0·0084	0·0054	0·0042	0·0025	0·0019	0·0048	0·0023	0·0030	0·0039	0·0028	0·0035	0·0023	0·0025	0·0033
352	,, ,,	,,	,,	15	25	*b*	0·0083	0·0041	0·0056	0·0030	0·0021	0·0030	0·0024	0·0033	0·0028	0·0029	0·0029	0·0018	0·0020	0·0032
323	Kodak *B10*	,,	Mains	15	20	*b*	0·0038	0·0033	0·0044	0·0036	0·0028	0·0025	0·0030	0·0026	0·0030	0·0029	0·0026	0·0016	0·0018	0·0031
324	,, ,,	,,	,,	15	20	*b*	0·0040	0·0043	0·0035	0·0033	0·0018	0·0038	0·0030	0·0039	0·0029	0·0025	0·0032	0·0029	0·0023	0·0031
325	,, ,,	,,	,,	15	20	*b*	0·0052	0·0041	0·0040	0·0026	0·0022	0·0032	0·0031	0·0027	0·0032	0·0036	0·0033	0·0023	0·0023	0·0032
328	Ilford Thinfilm Half-tone	,,	,,	15	60	*b*	0·0036	0·0045	0·0032	0·0016	0·0039	0·0017	0·0015	0·0029	0·0018	0·0009	0·0016	0·0006	0·0011	0·0029
329	,, ,,	,,	,,	15	60	*b*	0·0046	0·0059	0·0019	0·0013	0·0029	0·0028	0·0007	0·0025	0·0019	0·0017	0·0021	0·0009	0·0015	0·0030
356	,, ,,	,,	Generator	15	75	*b*	0·0038	0·0035	0·0044	0·0011	0·0029	0·0022	0·0007	0·0016	0·0016	0·0028	0·0019	0·0013	0·0013	0·0029
359	,, ,,	,,	,,	15	75	*b*	0·0018	0·0034	0·0046	0·0022	0·0018	0·0024	0·0017	0·0018	0·0016	0·0011	0·0018	0·0008	0·0013	0·0030
343	Ilford Ordinary	,,	Mains	15	30	*b*	0·0074	0·0055	0·0062	0·0033	0·0051	0·0069	0·0057	0·0076	0·0071	0·0083	0·0071	0·0051	0·0059	0·0036
344	,,	,,	,,	15	30	*b*	0·0078	0·0065	0·0097	0·0048	0·0051	0·0059	0·0043	0·0056	0·0048	0·0091	0·0069	0·0043	0·0049	0·0036

* This electrode was sharpened to an approximately 80° point. In the case of the steel auxiliary electrode, the normal steel-block main electrode was replaced by a flat-ended pencil.
† Two superimposed exposures were made for each spectrogram.

as indicated earlier. For this purpose four typical plates covering high to low plate variability were read with and without regard to this feature, in the latter case reading strictly in the top and bottom positions with disregard of all minor defects other than obvious mechanical damage to the plates. Comparison of the results for σ_{PC} and σ_{SC} is made in Table V. It is seen that the effect on σ_{SC} is not great, but is more serious in the case of σ_{PC}, especially with the Kodak *B*20 type of plate which appears to be particularly liable to these minor markings. It is interesting to note that the very high plate variability of the Ilford Ordinary type is not essentially due to such defects, but is apparently connected with variable emulsion response not detected visually as any form of discontinuity or defect.

The 31 plates forming the main series in the present work included the following types : Eastman Kodak Spectrum No. 1, Kodak *B*20, *B*10, and *B*5, and Ilford Ordinary and Thin-film Halftone. Fourteen *B*20 plates were used to study the effect of presparking for 15 sec. and of modifications in the electrode system. Comparison was made between the use of silver and graphite auxiliary electrodes with the normal steel sample and with $\frac{1}{4}$-in. dia. pencil samples cut from the steel test-block. In the case of the pencil samples, the lower electrode was used with a flat end. The upper, auxiliary electrode was in all cases used with an 80° point. The lowest values of σ_{SC} being obtained with graphite auxiliary electrodes and presparking, these conditions were standardized for the work with the other plates. Besides characterizing these various plates in relation to one another, the *B*5 and Thin-film plates also covered variation in the power feed, the high-voltage transformer being fed in a number of cases from a $6\frac{1}{2}$-kVA. synchronous motor-generator instead of normally from the mains through a 10-kVA. Ferranti moving coil, type *B* voltage regulator. The main details and standard deviations for the series are summarized in Table VI, the plates being arranged in chronological order within groups of the same type.

Consideration of Results of Main Investigation

The standard deviations σ_{PC} and σ_{SC} are best studied after regrouping as in Tables VII and VIII. In the first of these the values for σ_{PC} are meaned (R.M.S.) for the various types of plate and development procedure, and in the second, values for σ_{SC} are meaned according to sparking procedure.

(a) *Plate Contribution*

Considering σ_{PC}, it may be noted that the mean photometer readings for the manganese and nickel line-pairs were 7/9 and 6/7 against 29/19, 20/24, and 15/16 for the silicon, chromium, and molybdenum line-pairs. Any significance in the rather lower mean values for the former might be related to their well-defined and darker nature compared to the other three, but there is evidently no great difference between the various line-pairs and positions on the plates corresponding to the wavelength range covered.

Comparing the different types of plate, it would appear that Eastman Kodak *S*1 and Kodak *B*5 and *B*10 plates give similar small-scale variability contributions. The Kodak *B*20 plates were a little inferior, and the Ilford Ordinary plates notably worse in this respect, but the Ilford Thin-film Halftone plates were by far the best of those tested.

(b) *Excitation Response*

Turning to σ_{SC} and considering the detailed results in Table VIII, there is seen to be a considerable amount of variability from plate to plate which is probably largely due to lack of precision in the excitation, an aspect which the authors are studying in relation to controlled-source units.

There will, of course, be a contribution to σ_{SC} from any plate variability not catered for in σ_{PC}, in so far as it is on a larger scale than the 1·7-mm.

Table VII—*Summary of Values for* σ_{PC}

Type of Plate	Number of Plates	Development (*a*) Plain Dish (*b*) Squeegee Method	Mean Values for σ_{PC}					
			Si	Mn	Cr	Ni	Mo	Mean
Kodak *B*20	1	*a*	0·0034	0·0029	0·0040	0·0036	0·0035	0·0035
Kodak *B*20	13	*b*	0·0038	0·0040	0·0041	0·0036	0·0036	0·0038
Eastman Kodak *S*1	1	*a*	0·0032	0·0025	0·0043	0·0039	0·0033	0·0035
Eastman Kodak *S*1	2	*b*	0·0023	0·0033	0·0033	0·0039	0·0030	0·0032
Kodak *B*5	5	*b*	0·0038	0·0022	0·0033	0·0031	0·0029	0·0030
Kodak *B*10	3	*b*	0·0032	0·0034	0·0031	0·0030	0·0028	0·0031
Ilford Thin-film Half-tone	4	*b*	0·0021	0·0010	0·0019	0·0015	0·0016	0·0019
Ilford Ordinary	2	*b*	0·0064	0·0049	0·0067	0·0061	0·0087	0·0070
Overall means	31	...	0·0037	0·0034	0·0039	0·0035	0·0038	0·0036

line lengths employed in the present work. The mean results in Table VIII give indication of the presence of such a contribution in the lowness of the mean values for Thin-film Half-tone plates and the corresponding high values for the Ilford Ordinary plates. Confirmation of this appears in some work carried out with plates exposed to light from a mercury-vapour lamp as used for plate-calibration purposes. Five such plates were taken, one each of Ilford Thin-film Half-tone, Kodak *B*5, and Kodak *B*20 types, and two Ilford Ordinary plates. These were read in the usual manner, but for the following line-pairs*:

3650·146 with 3649·0
3663·276 with 3654·833,

the " element " line being given first in each case, and the comparison line second. Results for σ_{PC} and " σ_{SC} " are given in Table IX, and show very erratic values for σ_{SC} in the case of the Ilford Ordinary plates. It is also of interest to note from these figures that for the other plates, the figures for " σ_{SC} " lie in the region of 0·0020, which is rather lower than the average nickel and molybdenum figures from the main series of spark-source spectrograms.

* Three of these lines are mercury-vapour lines, but the line at 3649·0, although of similar intensity to the mercury lines, is not listed as a mercury line in Harrison or the other tables which we have consulted, and we have not been able to find corroborative evidence as to its being any of the other possible elements having lines in this neighbourhood. Average photometer readings for the four lines were, in order of ascending wavelength, 8, 7, 9 and 10 cm.

Returning to Table VIII, in spite of the complication from residual plate contribution to σ_{SC} and the tendency for appreciable variability from plate to plate, certain general conclusions can be drawn. Thus the use of steel-pencil electrodes was definitely the least satisfactory of the electrode systems tested. In view of the fluctuations in σ_{SC} from plate to plate for generally similar sparking conditions, it would be unsafe to attempt detailed comparison of the values of σ_{SC} for individual line-pairs as between the graphite and silver auxiliary electrodes. There is probably not a great deal of difference in overall response, but the two plates with presparking and silver electrodes suggest the possibility of slightly greater variability with the silver. Presparking appears to give steadier results with both. In regard to excitation, there is no indication of any improvement from the use of the synchronous generator in place of the normal regulated mains feed to the source unit. At the bottom of Table VIII values are given for the means of the 20 plates, other than Ilford Ordinary type, taken with graphite auxiliary electrodes and presparking. The Ilford Ordinary plates were omitted because of the probable relatively high contribution from plate variability still present in σ_{SC}. The results indicate values for σ_{SC} of the order of 0·0050 for silicon, 0·0045 for manganese and chromium, and 0·0025 for nickel and molybdenum.

In considering these mean results it will be noted that the low figures for σ_{SC} are associated with line-pairs made up from similar types of line, the nickel line-pair being of the un-ionized (I)

TABLE VIII—*Summary of Values for* σ_{SC}

Type of Plate	Number of Plates	Source of Current	Auxiliary Electrode	Pre-spark, sec.	Exposure, sec.	Mean Values for σ_{SC}					
						Si	Mn	Cr	Ni	Mo	Mean
Kodak *B*20	2	Mains	Steel pencil	0	10	0·0083	0·0084	0·0099	0·0043	0·0042	0·0074
,,	2	,,	,,	15	10	0·0065	0·0099	0·0086	0·0039	0·0034	0·0070
,,	2	,,	Silver	0	15	0·0080	0·0076	0·0061	0·0044	0·0023	0·0061
,,	2	,,	,,	15	15	0·0036	0·0073	0·0054	0·0043	0·0036	0·0049
,,	2	,,	Graphite	0	20	0·0072	0·0065	0·0076	0·0034	0·0048	0·0061
,,	4	,,	,,	15	15	0·0063	0·0047	0·0054	0·0029	0·0030	0·0046
Kodak *B*10	3	,,	,,	15	20	0·0044	0·0039	0·0040	0·0032	0·0023	0·0036
Kodak *B*5	2	,,	,,	15	30–40	0·0047	0·0032	0·0050	0·0018	0·0031	0·0037
,,	3	Generator	,,	15	20–30	0·0071	0·0048	0·0044	0·0028	0·0024	0·0046
Eastman Kodak *S*1	3	Mains	,,	15	15–20	0·0044	0·0056	0·0051	0·0038	0·0015	0·0043
Ilford Thin-film Half-tone	2	,,	,,	15	60	0·0041	0·0042	0·0026	0·0015	0·0034	0·0033
,, ,,	2	Generator	,,	15	75	0·0037	0·0035	0·0045	0·0017	0·0024	0·0033
Ilford Ordinary	2	Mains	,,	15	30	0·0076	0·0060	0·0081	0·0041	0·0051	0·0071
Means for graphite auxiliary electrode and 15-sec. prespark, excluding Ilford Ordinary plates:						0·0051	0·0043	0·0045	0·0027	0·0027	0·0040

TABLE IX—σ_{PC} *and* " σ_{SC} " *for Mercury-Vapour Lamp Lines*

Plate	Exposure, sec	σ_{PC}			" σ_{SC} "	
		Means from Main Series of Plates	3650·146 3649·0	3663·276 3654·833	3650·146 3649·0	3663·276 3654·833
Kodak *B*5 (*RXB*390)	40	0·0022 −0·0038	0·0021	0·0033	0·0019	0·0017
Kodak *B*20 (*RXB*389)	20	0·0036 −0·0041	0·0029	0·0042	0·0026	0·0024
Ilford Thin-film Half-tone (*RXB*386)	60	0·0010 −0·0021	0·0014	0·0018	0·0017	0·0021
Ilford Ordinary (*RXB*388, *RXB*391)	30	0·0049 −0·0087	0·0046 0·0060	0·0047 0·0065	0·0032 0·0052	0·0060 0·0037

type and the molybdenum of the singly ionized (II) type. The silicon and chromium line-pairs, on the other hand, are both mixed (I) (II) pairs, the manganese line being of unspecified type (Harrison). It was considered probable that some of the better reproducibility in the case of nickel and molybdenum would be attributable to the use of similar types of line, and this aspect was therefore explored in more detail.

From unpublished work which the authors have in hand in regard to source equipment, it was known that in some cases very great variability in log-ratio occurs with lines of mixed types, even though both lines originate from a single element. In this respect the behaviour of (II) (II) and (I) (II) iron line-pairs can be closely similar to that of comparable pairs of element-iron lines, indicating that the greater part of the variability is due to causes other than segregation or differences in response as between different elements. For these comparisons the authors have used the (I) (II) iron line-pair given by Grossman, Sawyer, and Vincent,* *i.e.* (*a*) Fe 2788·1 (I), (*b*) Fe 2793·9 (II), together with the line (*c*) Fe 2799·3 (II).

These lines were used in the combinations a/b and c/b to give dissimilar and similar line-pairs respectively. To reduce the amount of reading involved, the lines were read once only for the normal top and bottom readings, and these were checked when differences in log-ratio greater than 0·010 were found. The normal residual reading error corrections used in the three-reading series have been employed. The results will be somewhat less accurate than with the triple-reading procedure, but the effect should be quite small in the case of σ_{SC}. Results for the three Thin-film Half-tone plates *RXB* 329, 358, and 359 are given in Table X, together with existing results for the normal silicon, nickel, molybdenum, and chromium line-pairs from these plates. The results confirm the expected improvement from the use of matched line-pairs, and a search was made for a satisfactory singly ionized Cr/Fe pair, in view of the particular interest of chromium in comparison with the results of the statistical work of Vincent and Sawyer on this element (*loc. cit.*).

Choice of such a line-pair is considerably complicated by the large number of possible interfering lines in steel spectra even with the dispersion of the large quartz instrument. Overlapping of chromium by iron lines may result in considerable loss of sensitivity, and overlapping of iron lines of different types will obviously defeat in some degree the object of this present search. The absence of suitable Fe (II) lines above 3300Å. narrowed the region of interest to that between 2700 and 3300Å. Working from the tables in Brode's "Chemical Spectroscopy," thirty-two Cr (II) lines were noted with intensities not less than 100. Detailed study of these in relation to availability of suitable comparison iron lines and absence of serious interference, with reasonable sensitivity, eventually reduced these to four, made up in line-pairs as follows :

	Cr(II)	Fe(II)	%Cr ≡ 0·010 log-ratio at 0·77% Cr content
(1)	2757·72	2751·12	0·050
(2)	2870·43	2868·45 2868·87	0·035
(3)	2877·99	2876·80	0·050
(4)	3339·80	3323·07	0·030

These compare with a sensitivity of 0·030% for 0·010 log-ratio for the normal Cr (II) 3408·76, Fe (I) 3404·36 pair.

Although, in regard to sensitivity, pair (4) appears rather more attractive than (2), the former has two disadvantages in that not only is the separation of the two lines excessive for ease of reading and similarity of plate response,

* *Journal of the Optical Society of America*, 1943, vol. 33, pp. 185–193.

TABLE X—*Comparison of Values for σ_{SC} for Various Line-Pairs on Three Thin-Film Half-Tone Plates*

Line-Pairs	Mean Photometer Readings,* cm.	% of Content ≡ 0·010 Log Ratio	Values of σ_{SC}†			
			*RXB*329	*RXB*358	*RXB*359	Mean
Fe 2799·29 II / Fe 2793·89 II	10 / 7	...	0·0017	0·0021	0·0021	0·0020
Fe 2788·11 I / Fe 2793·89 II	10 / 7	...	0·0026	0·0035	0·0027	0·0030
Ni 3515·05 I / Fe 3513·82 I	7 / 8	3·5	0·0013	0·0011	0·0022	0·0016
Mo 2816·15 II / Fe 2813·61 II	18 / 20	3·5	0·0029	0·0029	0·0018	0·0026
Si 2881·58 I / Fe 2885·93 II	32 / 22	4·0	0·0046	0·0038	0·0018	0·0036
Cr 3408·76 II / Fe 3404·36 I	21 / 25	4·0	0·0024	0·0044	0·0046	0·0039
Cr 2870·43 II / Fe 2868·87, 2868·45 II	26 / 22	4·5	0·0024	0·0021	0·0017	0·0021
Cr 3021·56 I / Fe 3016·18 I	33 / 31	8·0	0·0027	0·0024	0·0018	0·0023

* Related to a 50-cm. clear emulsion reading.

† Based on single readings for the Fe line-pairs and the CrII/FeII pair, and on the standard means of three readings elsewhere, the CrII/FeI pair on *RXB*329 being from two such sets of three readings.

but also there is a wider variation between iron and chromium densities, with the chromium of lower density than desired. The lines of pair (2) closely resemble the normal pair in regard to density level and difference. Preliminary examination for σ_{SC} indicated that pair (2) would in fact prove superior, and this pair was therefore chosen for quantitative comparison with the normal line-pair, in respect of conditions including Thin-film Half-tone plates and graphite auxiliary electrodes with 15-sec. presparking. Plates *RXB* 329, 358, and 359 were read and the results are included in Table X. They confirm that with this line-pair values of the order of 0·0020 may be expected for σ_{SC}.

The possibility also arises of improved results from the use of un-ionized lines, the good results for nickel being obtained with such a pair. The choice of un-ionized lines is very considerably restricted by their low intensity under the conditions of excitation used and the only suitable chromium line found in the region used by the authors was Cr (I) 3021·56. This was combined with the line Fe (I) 3016·18. Results for this line-pair are also included in Table X, from which it will be seen that it gave results of a similar order, but not quite as good as those from the Cr (II)–Fe (II) pair. Moreover, this latter pair has the advantage over the un-ionized lines in regard to sensitivity with a change of 0·035% of chromium for 0·010 log " intensity " ratio as compared with 0·060% of chromium for the un-ionized pair.

(c) *Reading Errors*

Reading error, expressed as σ_R, has remained within the limits 0·0026 and 0·0033, except for the value of 0·0036 obtained with the Ilford Ordinary plates. This last is considered attributable to the higher variability in plate response over small areas with this type of plate which is liable to introduce an abnormal variability from small differences in positioning for repeat readings. Any other significant variations are apparently related to time of reading rather than to type of plate, and are probably connected with day-to-day variations in the behaviour of equipment.

The value of reading errors in normal working will, of course, depend upon the method of reading. For individual readings of 0·5-mm. lengths of line, σ_R can be used as the appropriate standard deviation. σ_R was based on the differences

TABLE XI—*Comparison of Reading Errors Estimated as* σ_R *and* σ_{R9}

Reading Error	*RXB*328			*RXB*305, Cr	*RXB*263, Cr	Mean
	Si	Cr	Ni			
σ_R	0·0028	0·0029	0·0034	0·0029	0·0024	0·0029
σ_{R9}	0·0032	0·0030	0·0033	0·0031	0·0029	0·0031

between the individual readings and the means of three readings, calculated as $\sqrt{\Sigma d^2/\frac{2}{3}n}$, where n is the total number of readings. However, the calculations regarding the residual reading errors, σ_{RT}, σ_{RP}, and σ_{RTM}, suggested that the use of $\frac{2}{3}n$ might give too large a value. On the other hand, in normal working, only one set of readings would be made, so that the check existing in the present series between repeat readings differing in log-ratio by more than 0·010 would be absent, with some possible resulting increase in reading error. In effect, therefore, σ_R would be expected to express the order of the normal reading error reasonably accurately.

A second approach to the reading error is possible, as in the case of the residual reading errors, by working with the means of nine readings, using the formula :

$$\sigma_{R9} = \sqrt{\frac{\Sigma d^2}{\frac{8}{9}n}}.$$

The values so obtained will tend to be a little high as against the σ_R series because checking for differences greater than 0·010 was carried out only for groups of three readings. The values given by the two methods are compared in Table XI. It is evident from these figures that the standard deviation for reading error in normal practice can be taken as of the order of 0·0030.

(d) *Miscellaneous*

Finally, from Table VI, the checking of the mean values for σ_{PMC} against $\sigma_{PC}/\sqrt{2}$ is of interest, because the σ_{PMC} values were calculated by a procedure involving all the other standard deviations except σ_R, including all three residual reading error corrections. The satisfactory correspondence between the two columns is, therefore, a useful check of the general working and assumptions.

ACCURACY ATTAINABLE UNDER VARIED CONDITIONS

From the figures for σ_{SC}, σ_{PC}, and σ_R, it is possible to deduce the total variability according to the relation :

$$\sigma_T = \sqrt{\sigma_{SC}^2 + \sigma_{PC}^2 + \sigma_R^2}$$

While the data obtained in terms of log-ratios showed the lowest variability for σ_{SC} for the use of graphite electrodes with presparking, this requires further consideration in terms of composition, since some changes in slope of the curves relating composition and log-ratio occur when using silver electrodes. Thus, in the case of chromium, the composition curve indicated that 0·010 log-ratio was equivalent to 0·024% of chromium with silver electrodes, but with graphite electrodes the value became 0·030%. To relate the variability figures to practice, therefore, it is necessary to compare σ_T in terms of percentage of the element content. This is done in Table XIII where the conversion is given for four sets of

TABLE XII—*Comparison of Actual Reproducibility for Thin-Film Half-Tone Plates, Graphite Auxiliary Electrodes, and 15-sec. Presparking,* with Calculated Expectations from Table XIII*

Element	σ_T (from Means of three Readings	σ_T Corrected to σ_{T1} for Single Readings†		Calculated Values of σ_{T1} from Table XIII	
	Log Ratio	Log Ratio	% of Content	Log Ratio	% of Content
Silicon (0·25)	0·0048	0·0053	2·3	0·0062	2·7
Manganese (0·58)	0·0046	0·0051	1·3	0·0058	1·6
Chromium (0·77)	0·0049	0·0054	2·1	0·0058	2·3
Nickel (2·75)	0·0031	0·0038	1·2	0·0044	1·4
Molybdenum (0·50)	0·0040	0·0045	1·6	0·0044	1·6
Mean	0·0043	0·0049	1·8	0·0054	2·0

* Plates 328, 329, 358, and 359.

† Calculated according to $\sigma_{T1} = \sqrt{\sigma_T^2 - \sigma_{RT}^2 + \sigma_R^2}$ where $\sigma_{RT} = 0·0021$ and $\sigma_R = 0·0030$.

TABLE XIII—*Estimated Reproducibility* (σ_{T1}) *with Varying Plates and Excitation Conditions and Single Readings of*

TABLE XIII—*Estimated Reproducibility (σ_{T1}) with Varying Plates and Excitation Conditions and Single Readings of 0·5-mm. Lengths of Line*

$\sigma_R = 0{\cdot}0030$ used throughout, and mean values of σ_{SC} for each type of exposure condition

Element	Content	Silver Auxiliary Electrode, no Presparking, Kodak *B*20 Plate ($\sigma_{PC} = 0{\cdot}0040$)				Silver Auxiliary Electrode, no Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)				Silver Auxiliary Electrode, 15-sec. Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)				Graphite Auxiliary Electrode, 15-sec. Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)			
		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	$\sigma_{T1} = \sqrt{\sigma_{SC}^2 + \sigma_{PC}^2 + \sigma_R^2}$		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	σ_{T1}		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	σ_{T1}		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	σ_{T1}	
				Log-Ratio	Content (%)			Log-Ratio	Content (%)			Log-Ratio	Content (%)			Log-Ratio	Content (%)
Si	0·25	0·009	0·0080	0·0094	0·0085	0·009	0·0080	0·0088	0·0079	0·009	0·0040	0·0054	0·0049	0·011	0·0050	0·0062	0·0068
Mn	0·58	0·016	0·0075	0·0090	0·0144	0·016	0·0075	0·0083	0·0133	0·016	0·0070	0·0079	0·0126	0·016	0·0045	0·0058	0·0093
Cr	0·77	0·024	0·0060	0·0078	0·0187	0·024	0·0060	0·0070	0·0168	0·024	0·0055	0·0066	0·0158	0·030	0·0045	0·0058	0·0174
Ni	2·75	0·090	0·0045	0·0067	0·0603	0·090	0·0045	0·0058	0·0522	0·090	0·0045	0·0058	0·0522	0·090	0·0025	0·0044	0·0396
Mo	0·50	0·016	0·0025	0·0056	0·0090	0 016	0·0025	0·0044	0·0070	0·016	0·0035	0·0050	0·0080	0·018	0·0025	0·0044	0·0079
Mean	...	...	...	...	2·5	...	...	...	2·3	...	...	...	2·0	...	...	...	2·0

Element	Content	Graphite Auxiliary Electrode, 15-sec. Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)			
		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	σ_{T1}	
				Log-Ratio	Content (%)
Si	0·25	0·009	0·0040	0·0054	0·0049
Mn	0·58	0·016	0·0070	0·0079	0·0126
Cr	0·77	0·024	0·0055	0·0066	0·0158
Ni	2·75	0·090	0·0045	0·0058	0·0522
Mo	0·50	0·016	0·0035	0·0050	0·0080
Mean	...	...	...	...	...

Element	Content	Graphite Auxiliary Electrode, 15-sec. Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)			
		Change in Content (%) $\equiv 0{\cdot}010$ in Log-Ratio	σ_{SC} (Log-Ratio)	σ_{T1}	
				Log-Ratio	Content (%)
Si	0·25	0·011	0·0050	0·0062	0·0068
Mn	0·58	0·016	0·0045	0·0058	0·0093
Cr	0·77	0·030	0·0045	0·0058	0·0174
Ni	2·75	0·090	0·0025	0·0044	0·0396
Mo	0·50	0·018	0·0025	0·0044	0·0079
Mean	...	...	...	...	...

Element	Content	Graphite Auxiliary Electrode, 15-sec. Presparking, Ilford Thin-Film Half-Tone Plate ($\sigma_{PC} = 0{\cdot}0020$)	
		σ_{T1}	
		Content (%)	% of Content
Si	0·25	0·0068	2·7
Mn	0·58	0·0093	1·6
Cr	0·77	0·0174	2·3
Ni	2·75	0·0396	1·4
Mo	0·50	0·0079	1·6
Mean	...	...	2·0

conditions, namely : (1) the original silver auxiliary electrode with no presparking and using *B*20 plates ; (2) a similar arrangement with Ilford Thin-film Half-tone plates ; (3) a graphite auxiliary electrode with 15-sec. presparking and Thin-film Half-tone plates ; and (4) a silver auxiliary electrode with presparking and Thin-film Half-tone plates. In all cases single readings of each line are assumed, σ_R being taken at 0·0030 throughout. It must be kept in mind that the deductions for silver electrodes are based on the results from only two plates in each case as against nineteen plates with graphite electrodes. Too much stress must not, therefore, be placed on apparent differences for particular elements, the mean values suggesting little overall differences in accuracy between the two types of electrodes.

It is interesting to compare the calculated results from Table XIII for graphite electrodes and presparking, with the mean results obtained from the four Ilford Thin-film Half-tone plates in the main series after correction for the higher reading error involved in single readings. This is done in Table XII which shows that the calculated values are somewhat higher than the corrected observed results.

The reason for this is the lower value of σ_{SC} for these plates as against the general average used in calculating the values given in Table XIII. Table XIV gives the observed differences between mean values for σ_{SC} for various types of plate and that for the Thin-film Half-tone plates. It is not certain how far these differences are due to increased contributions from plate variability over larger areas not covered by σ_{PC}, but they presumably reflect this, indicating appreciable increases, least in the case of the Kodak *B*10 plates and greatest for the Ilford Ordinary plates. Comparison of the σ_{T1} figures in Table XII shows a mean drop in terms of log-ratio from 0·0054 to 0·0049 for the Thin-film Half-tone plates as against the general average, corresponding to a

TABLE XIV—*Difference in Variability Included in σ_{SC} Between Ilford Thin-Film Half-Tone and other Plates Tested (for Graphite Auxiliary Electrode and 15-sec. Prespark Series)*

Type of Plate	No. of Plates	Mean σ_{SC} (5 Elements)	Mean Increased Variability in σ_{SC} over that for Thin-Film Half-Tone Plates
Ilford Thin-Film Half-Tone	4	0·0033	...
Eastman Kodak *S*1	3	0·0043	0·0028
Kodak *B*5	5	0·0043	0·0028
Kodak *B*10	3	0·0036	0·0014
Kodak *B*20	4	0·0046	0·0032
Ilford Ordinary	2	0·0071	0·0063

TABLE XV—*Comparison of Mean Log-Intensity Ratios Calculated from the Upper and Lower Readings from 30 Spectrograms*

Plate	Element	Lower Reading	Upper Reading	Difference
*RXB*263 (Kodak *B*20)	Chromium	$\bar{1}\cdot9354$	$\bar{1}\cdot9337$	$+0\cdot0017$
*RXB*305 (Kodak *B*5)	Chromium	$\bar{1}\cdot9251$	$\bar{1}\cdot9237$	$+0\cdot0014$
*RXB*328 (Ilford Thin-film Half-tone)	Chromium	$\bar{1}\cdot9287$	$\bar{1}\cdot9284$	$-0\cdot0003$
Mean of above	Chromium	...	...	$+0\cdot0009$
*RXB*328	Silicon	0·1740	0·1749	$-0\cdot0009$
*RXB*328	Nickel	1·9637	1·9636	$-0\cdot0001$

standard deviation of 0·0020. The mean reproducibility figures given in Table XV have been obtained from the Table XIII values by application of a correction to this amount.

In considering these figures it must be borne in mind that lower values of σ_{SC} would be expected for the first three elements from suitable line-pairs of matched types. As already indicated when considering σ_{SC}, the choice of a suitable pair for chromium gave values of σ_{SC} of a similar order to those for nickel and molybdenum. At 0·0020 for a series of Thin-film Half-tone plates taken with graphite electrodes and presparking, this corresponded to an overall reproducibility of the order of 1·9%. With such low values of σ_{PC} and σ_{SC} reading errors obviously become increasingly important.

COMPARISON OF PRESENT REPRODUCIBILITY RESULTS WITH DATA BY VINCENT AND SAWYER

It is of considerable interest to compare the standard deviations from the present work with those given by Vincent and Sawyer in their 1942 paper (*loc. cit.*). Conversion into comparable terms is necessary, and certain differences in procedure and working must be taken into account.

Considering first the microphotometry contribution, the Vincent and Sawyer figure of $\sqrt{2} \times 0\cdot18$, or 0·25% of content compares with σ_R. This has been estimated at 0·0030 on log "intensity" ratio in the present data, which in terms of percentage content becomes :

(*a*) $0\cdot0030 \times \dfrac{0\cdot24 \times 100}{0\cdot100 \times 0\cdot77} = 0\cdot94\%$ of content for silver electrodes.

(*b*) $0\cdot0030 \times \dfrac{0\cdot30 \times 100}{0\cdot100 \times 0\cdot77} = 1\cdot17\%$ of content for graphite electrodes.

Turning to the excitation response, σ_{SC}^2 in the present work corresponds to the Vincent and Sawyer values for $\sigma_S^2 + \sigma_h^2$ where σ_S is the spectroscopic source error, given as 0·46% of the content, and σ_h the inhomogeneity error, estimated at 0·20% of the content. This gives a figure corresponding to σ_{SC} of 0·50%. Mean values for σ_{SC} from the present data (Table XIII) are :

(*a*) $0\cdot0055 \times \dfrac{0\cdot24 \times 100}{0\cdot100 \times 0\cdot77} = 1\cdot71\%$ of content for silver electrodes with presparking.

(*b*) $0\cdot0045 \times \dfrac{0\cdot30 \times 100}{0\cdot100 \times 0\cdot77} = 1\cdot75\%$ of content for graphite electrodes with presparking.

It has been noted, however, that the results with the Ilford Thin-film Half-tone plates indicate values lower than these averages by an amount corresponding to a standard deviation of 0·0020. Reduction by this amount in the case of (*a*) gives :

$$0\cdot0051 \times \frac{0\cdot24 \times 100}{0\cdot100 \times 0\cdot77} = 1\cdot59\% \text{ of content,}$$

and for (*b*) :

$$0\cdot0040 \times \frac{0\cdot30 \times 100}{0\cdot100 \times 0\cdot77} = 1\cdot52\% \text{ of content.}$$

Vincent and Sawyer, however, do not specify the type of the line-pair used to obtain their results, and it must be assumed that this may have consisted of matched lines, as in the case of the singly ionized line-pair Cr 2870·43, Fe 2868·87 (0·45) used by the present authors. For comparison under such conditions the anticipated value of σ_{SC} for such a pair under the present conditions of operation must be included. Using the value 0·0020 for σ_{SC}, for the graphite auxiliary electrodes and presparking, we get :

$$\sigma_{SC} = 0\cdot0020 \times \frac{0\cdot35 \times 100}{0\cdot100 \times 0\cdot77}, \text{ or } 0\cdot91\% \text{ of the content.}$$

The change in sensitivity for this line-pair also modifies the figure for microphotometry contribution when expressed in terms of percentage of content, the value with graphite electrodes becoming :

$$0\cdot0030 \times \frac{0\cdot35 \times 100}{0\cdot100 \times 0\cdot77}, \text{ or } 1\cdot36\% \text{ of the content.}$$

Finally we have σ_{PC} which compares with

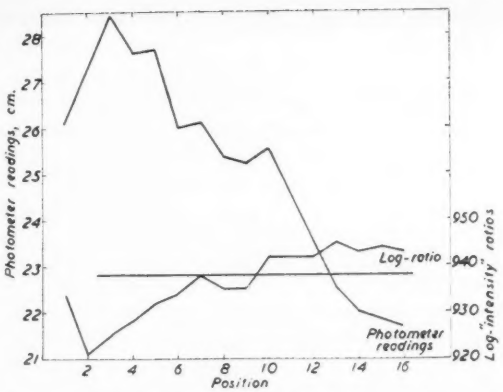


FIG. 1—Means of Fe-line readings and log-ratios for chromium, for 0·5-mm. line lengths from 18-mm. wide spectrograms

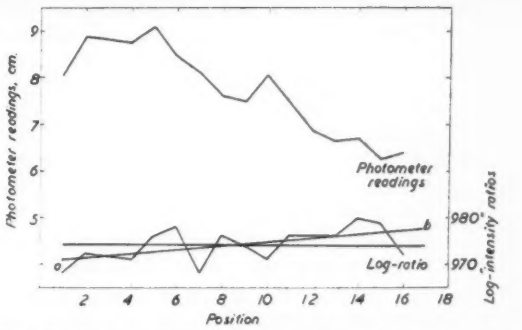


FIG. 2—Means of Fe-line readings and log-ratios for nickel, for 0·5-mm. line lengths from 18-mm. wide spectrograms

$\sqrt{2}\sigma_P$ from Vincent and Sawyer's work, since two lines are involved in each log-ratio. Before this can be properly considered, however, it is necessary to examine the derivation of σ_P in the American work. It is there taken from a series of readings of an unspecified line from 135 spectrograms, apparently from 13 different plates, the number on each plate varying from five to seventeen. Readings R_1 and R_2 were made on mutually exclusive portions of each line, and D_1 and D_2 represent the differences between these values in successive spectrograms. These authors state that, in their practice, imperfection of imaging by the spectrograph gives rise to slightly different intensities for the two regions examined, and that a correction for this may be introduced by multiplying one set of readings by a factor K to render the sum of the readings equal for both sets for a given plate. In fact, they apply the correction to D_1, based on the relative magnitudes of ΣD_1 and ΣD_2 for each plate. They then calculate σ_3 as $[\Sigma(KD_1 - D_2)^2/4n]^{\frac{1}{2}}$ σ_3 being related to σ_P according to $\sigma_P = (\sigma_3^2 - \sigma_M^2)^{\frac{1}{2}}$, where σ_M is the predetermined microphotometry error.

The drift of the $\Sigma R_1/\Sigma R_2$ ratio across the 13 plates appears to be of a generally random nature, but the correction applied is large in relation to the value of σ_P. For comparison with the present work the data has been recalculated on the basis of:

$$\sigma_3{}^1 = \left[\frac{\Sigma(K'R_1 - R_2)^2}{2n} \right]^{\frac{1}{2}}$$

where $K' = \Sigma R_1/\Sigma R_2$.

This gives a rather higher value of 0·067 cm., as against the Vincent and Sawyer figure of 0·052 cm. Omission of the factor K', however, raises this standard deviation to 0·186 cm., and in view of the very considerable contribution from the "imaging" effect in the American work, examination has been made for the presence of any such effect as between upper and lower readings in the present investigation. In the first place, examination was made of drifts across 18-mm. wide spectrograms. Four such spectrograms were taken on a single Kodak *B*20 plate, and were each read over sixteen separate 0·5-mm. lengths for the nickel–iron and chromium–iron line-pairs. Mean iron-line readings are plotted against position in Figs. 1 and 2. They show a definite drift in the same general direction. The corresponding graph for log-ratios shows more erratic behaviour, but the means plotted in Figs. 1 and 2, suggest a trend which is much more pronounced for chromium than for nickel. In order to obtain an approximation for the effect of this in practice, the mean straight lines *a*, *b* were drawn.* These lines indicate a mean correction to log-ratio between adjacent 0·5-mm. lengths of 0·002 for the chromium–iron line-pair, and of considerably less than 0·001 for the nickel–iron line-pair.

A more direct estimate of the effect on actual working has been made with the readings used in the nine-reading series, namely, for chromium on *RXB*263 and *RXB*305 and for silicon, chromium, and nickel from *RXB*328. The means of the nine readings were used, the overall mean of the lower readings being compared with the corresponding mean of the upper readings in each case. The results, given in Table XV, suggest that a correction of 0·001 should be subtracted from the lower readings for chromium and added to the lower readings for silicon. The correction for nickel would appear to be negligible. Table XVI gives comparative values for σ_{P9} before and after applying these corrections. It is clear that the effect is quite small when dealing with deviations of the magnitude of those encountered in the present work, and should not appreciably

*The first two readings for chromium were omitted because of abnormality.

TABLE XVI—*Effect on σ_{P9} of Correction for Mean Differences Between Upper and Lower Readings Indicated in Table XV*

Plate	Element	Correction to Lower Reading	σ_{P9} with Correction	σ_{P9} without Correction
*RXB*263 Kodak *B*20	Chromium	−0·001	0·0050	0·0051
*RXB*305 Kodak *B*5	Chromium	−0·001	0·0035	0·0036
*RXB*328	Chromium	−0·001	0·0028	0·0027
Ilford Thin-film Half-tone	Silicon	+0·001	0·0022	0·0023

affect comparison between plates. No " imaging " correction has, therefore, been applied to the present results.

The value of 0·067 cm. calculated for σ_3' above is converted to percentage content by the factor $(0{\cdot}18/0{\cdot}027)\sqrt{2}$ from the Vincent and Sawyer data, giving 0·63%. This compares with σ_{PC} in the present work, which for Ilford Thin-film Half-tone plates gave :

(*a*) $0{\cdot}0020 \times \dfrac{0{\cdot}24 \times 100}{0{\cdot}100 \times 0{\cdot}77} = 0{\cdot}62\%$ of content for silver electrodes.

(*b*) $0{\cdot}0020 \times \dfrac{0{\cdot}30 \times 100}{0{\cdot}100 \times 0{\cdot}77} = 78\%$ of content for graphite electrodes.

In the case of the new chromium–iron line-pair, this latter becomes :

$$0{\cdot}0020 \times \frac{0{\cdot}35 \times 100}{0{\cdot}100 \times 0{\cdot}77} = 0{\cdot}91\% \text{ of content.}$$

In considering these relative plate contributions, it should also be borne in mind that in the present work the area of plate photometered has been $0{\cdot}15 \times 0{\cdot}5$ mm. or $0{\cdot}75 \times 10^5$ sq. microns. Vincent and Sawyer, on the other hand, refer to an area of $1{\cdot}4 \times 10^5$ sq. microns. A somewhat smaller deviation would, therefore, be expected from their results for equivalent plates.

Comparison between the best results in the present work and figures deduced from the data in the Vincent and Sawyer paper are summarized in Table XVII. It is seen that the plate contribution in the present work is only slightly greater than the American figure, but that the sparking-response contribution is appreciably higher, and the microphotometry error considerably greater, than the figures indicated by the American authors. With decreasing values for plate and sparking-response contributions, accurate microphotometry becomes of increasing importance and it is of interest to note that the very low standard deviation from this source of 0·18% of content estimated by Vincent and Sawyer corresponds to a reading error of only about $\frac{1}{4}$ mm. on individual readings under the present authors' conditions with a 50-cm. full-scale deflection.

SUMMARY

Preliminary work with nine samples of $2\frac{3}{4}\%$ nickel – chromium – molybdenum steel, seven samples being analysed and two used as standards, gave figures for standard deviation in terms of percentage of the element content ranging from 2·6 for nickel to 5·2 for silicon, based on means of duplicate spectrograms. Variations in agitation and in the use of a wetting agent during development produced no significant changes.

To permit analysis of the results for the variability contribution from various sources, the main study has been based on repetition work

TABLE XVII—*Comparison of Standard Deviations for Repetition Work on Chromium in the Present Investigation, with Corresponding Figures from Data by Vincent and Sawyer**

Source of Deviation:	Standard Deviation (as % of Content)		
	Present Work†		Vincent and Sawyer's Data*
	Cr 3408·76 II Fe 3404·36 I	Cr 2870·43 II Fe 2868·45 II Fe 2868·87 II	Cr 2822·01 Fe 2811·27
Sparking response	1·52	0·91	0·50
Small-scale plate variability	0·78‡	0·91‡	0·63§
Microphotometry	1·17	1·36	0·25
Total	2·07	1·87	0·84

* Using two steel electrodes and 5-sec. pre-sparking, but type of plate not specified.

† Using graphite auxiliary electrodes, 15 sec. for sparking, and Ilford thin-film half-tone plates.

‡ Based on measurement of $0{\cdot}5 \times 0{\cdot}15$ mm. of plate surface.

§ Recalculated figure, based on the method of the present investigations, but with correction for differences between ΣR_1 and ΣR_2 for each plate.

with a single sample. This had the following composition :

C,%	Si,%	Mn,%	Cr,%	Ni,%	Mo,%
0·30	0·25	0·58	0·77	2·75	0·50

and was used for taking 31 plates. From each plate 30 spectrograms were read, involving upwards of 9000 lines and some 60,000 individual readings.

Variations included excitation conditions, while type of plate, development, and microphotometry errors were also studied. Statistical examination of the results has permitted analysis of the variability for the contribution from the three main sources : (1) Excitation response, (2) small-scale plate variability, and (3) microphotometry errors.

Excitation Response (σ_{SC})

Excitation was by means of the normal Hilger equipment, consisting of a 15,000-V. transformer, with a 0·005-μF. condenser and no added inductance. Variations studied were mainly concerned with the auxiliary electrode and the influence of presparking for 15 sec. The auxiliary electrodes used were silver and graphite rods and steel pencils cut from the actual sample, all of which had 80° points sparking against a flat surface on the sample. A further variation consisted in the use of a synchronous motor-generator to feed the excitation unit in place of the normal voltage regulator.

No significant alteration was found from the use of the synchronous generator. The greatest variation occurred with metal-pencil auxiliary electrodes, and, based on log " intensity " ratios, the lowest variability was given by graphite auxiliary electrodes with presparking. Advantage in this latter case was partly offset by a decrease in the rate of change of log-ratio, with composition in the case of some elements, as compared with the use of silver auxiliary electrodes.

From the whole series of results for graphite electrodes with presparking, values for standard deviation in terms of log-ratio were obtained of the order of 0·0050 for silicon, 0·0045 for manganese and chromium, and 0·0025 for nickel and molybdenum.

These lower values for nickel and molybdenum are considered to be largely due to the use of line-pairs made up from similar types of line free from serious interference by overlapping or adjacent lines. It has been shown that variability of similar order occurs even when both lines of the line-pair are iron lines, and that suitable choice of a chromium–iron line-pair reduced the standard deviation for this element to a similar level to those obtained for nickel and molybdenum or a matched pair of iron lines.

There is evidence, however, that these values for σ_{SC} include a contribution from plate variability over larger areas than those explored by σ_{PC}, this contribution being least for the Ilford Thin-film Half-tone plates, and greatest for Ilford Ordinary plates. Based on σ_{SC}, the differences in variability between the Thin-film Half-tone and the other plates tested ranged from standard deviations of 0·0014 for Kodak *B*10 to 0·0063 for Ilford Ordinary plates. The results for σ_{SC} obtained with the Thin-film Half-tone plates were thus appreciably lower than average, values of from 0·0039 for silicon to 0·0016 for nickel being obtained from the four plates of this type examined in the graphite auxiliary electrode series.

Microphotometry (σ_R) *and Plate Variability* (σ_{PC})

For the microphotometry error an average value of the order of 0·0030 in terms of log-ratio is to be anticipated for the reading procedure used.

Plate variability was studied in respect of variability over small areas by reading independent 0·5-mm. lengths from the 1·7-mm. lines. The results show the Ilford Thin-film Half-tone plate to be decidedly better in this respect than any of the other plates used, with a value for the standard deviation from this source of the order of 0·0020 in terms of log-ratio. This compares with 0·0030 for Kodak *B*5 and *B*10 and Eastman Kodak *S*1 types, and with a little under 0·0040 for Kodak *B*20 plates. The least satisfactory plate from this angle was the Ilford Ordinary with a figure of 0·0070.

No significant difference was found between development with initial agitation only, and continuous agitation with Kodak-type metal-blade " squeegee."

As indicated above, when considering excitation response, there is an indication of additional variability over larger distances, least in the case of the Ilford Thin-film Half-tone plates, and greatest for the Ilford Ordinary plates.

Total Variability (σ_{T_1})

The total variability can be estimated for various conditions by the relation :

$$\sigma_{T_1} = \sqrt{\sigma_{SC}^2 + \sigma_{PC}^2 + \sigma_R^2}$$

The following figures, in terms of percentage of content, compare the mean results for :

(*a*) The original combination of silver auxiliary electrode, no presparking, and Kodak *B*20 plates.

(*b*) The use of silver auxiliary electrodes with 15-sec. presparking and Ilford Thin-film Half-tone plates.

(*c*) The use of graphite auxiliary electrode with 15-sec. presparking and Ilford Thin-film Half-tone plates :

	(*a*)	(*b*)	(*c*)
Silicon	3·4	1·8	2·6
Manganese	2·5	2·1	1·5
Chromium	2·4	2·0	2·1
Nickel	2·2	1·8	1·3
Molybdenum ...	1·8	1·5	1·4
Mean	2·5	1·9	1·8

By using a new chromium–iron line-pair, consisting of two singly ionized lines, the standard deviation under (*c*) was reduced to 1·9%.

Comparison of Reproducibility Figures with Vincent and Sawyer's Data

In spite of the improvements resulting from the use of presparking, Ilford Thin-film Half-tone plates, and the new Cr (II)–Fe (II) line-pair, the total variability figure of 1·9% of content is still considerably higher than the 0·7% given by Vincent and Sawyer.

With the original Cr (II)–Fe (I) line-pair, the major source of variability under the present authors' conditions was in the sparking response at 1·5% of the content, compared with the American 0·5%. With the new Cr (II)–Fe (II) pair this decreased to 0·9%, leaving the major contribution from the microphotometry at 1·4%, compared with the 0·25% reported by Vincent and Sawyer. Small-scale plate variability then contributed 0·9% as compared with 0·8% for the original line-pair, and 0·6% calculated from Vincent and Sawyer's data, though the American authors' figures probably referred to an appreciably larger area of plate than the $0{\cdot}75 \times 10^5$ sq. microns used in the present work.

From consideration of these results the very low microphotometry error given by the American authors is of special interest, and it is to be noted that their figure of 0·18% of content for the standard deviation in individual line readings corresponds to only a quarter of a millimetre scale reading under the present authors' conditions.

ACKNOWLEDGMENTS

The authors wish to acknowledge the encouragement which they have received in this study from Dr. C. Sykes, F.R.S., Technical Director of Messrs. Thos. Firth and John Brown, Ltd., and to the Directors of that company for permission to make known the results.

APPENDIX I—*Details of Procedure in Preliminary Work*

The samples were in the form of 7-lb. box test-ingots ground to a flat about $\frac{1}{4}$ in. wide along a bottom edge and filed to remove grinding marks. Silver rods, $\frac{3}{16}$ in. in dia. with 80° points, were used as auxiliary electrodes, with a spark gap of $2\frac{1}{2}$ mm. This gap was arranged at 38 cm. from the slit, which had a width of 0·015 mm., the height of individual spectrograms being 1·7 mm. The wavelength range setting was 2700 to 4300Å. A 15,000-V. Hilger transformer, with 0·005-μF. capacity and no added inductance, was employed for excitation. Two superimposed 20-sec. exposures were used for each spectrogram.

The plates were Kodak *B*20 type, and development was carried out in a 10 × 8-in. dish in 300 c.c. of Kodak *D*19*b* developer at 18° C. for 4 min., the details of development being modified as indicated in the text.

The following line-pairs were used :

Element	Element Line	Comparison Iron Line
Silicon	2881·58 I	2885·93 II
Manganese ...	2933·06 –	2936·90 I
Chromium ...	3408·76 II	3404·36 I
Nickel	3515·05 I	3513·82 I
Molybdenum ...	2816·15 II	2813·61 II

Reading was carried out on a model *H*451.306 Hilger photometer, using the compact galvanometer scale unit. The concentrated light beam was used for reading, and the photometer slit was set at 0·15 mm. width to read a 0·5-mm. length of line from the 1·7 mm. available.

In the absence of defects or damage, these readings were made centrally on the lines.

APPENDIX II—*Development Procedure on the Lines of the Kodak Multiple-Blade Squeegee Technique*

Based on Kodak Data Sheet *A*22 of May 1941, and discussion at the Kodak Research Laboratories, a dish and squeegee were constructed for carrying out developments according to the Kodak Multiple-Blade Squeegee Procedure.

The dish was 15 × 12 in., made of 18/8 chromium–nickel steel, and had a removable bottom-plate with guides for the squeegee and locating strips for the plate. The plate rested with its shorter edges along the locating strips, being approximately centred in the other direction by the operator. The general appearance of the steel bottom-plate, with a photographic plate in position is shown in Fig. 3.

The squeegee itself had eleven 18/8 chromium–nickel stainless-steel blades, $10\frac{3}{4} \times 1$ in. × 19 gauge, set $\frac{5}{8}$ in. apart in bakelite end-pieces and carried by a wooden handle. The blades were parallel with the long edges of the plate at about $\frac{1}{4}$ in. above its upper surface. The general appearance of the squeegee is shown in Fig. 4.

In practice, $1\frac{1}{2}$ litres of developer were used and the squeegee was given a complete to-and-fro

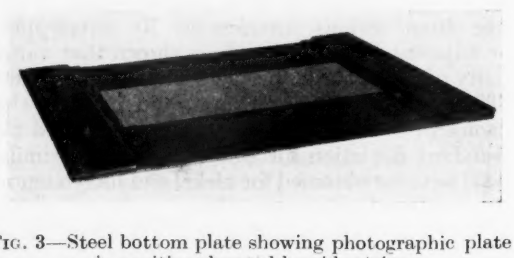


FIG. 3—Steel bottom plate showing photographic plate in position, located by side strips

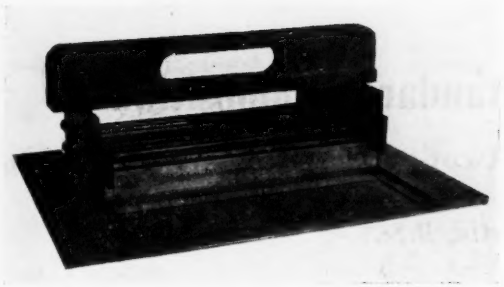


FIG. 4—General appearance of squeegee

movement from side to side of the dish 28–30 times a minute. The outer dish was placed in a water bath to maintain a steady temperature. The plate was immersed flat, and each long edge was alternately raised twice to ensure even wetting, after which it was centred and the squeegee inserted. Oscillation commenced at 15 sec., and development was continued to a total of 3½ min.

The developer used was Kodak *D19b* at one-quarter normal strength.

APPENDIX III—*Schedule of Standard Deviations Used*

Total Variability

This was based on variation of individual log "intensity" ratios from the mean of the series in question and is indicated by the suffix *T*. It includes the total excitation response and plate contributions, but variable proportions of microphotometry error, according to the method of derivation and correction.

- σ_T relates to means of three individual readings from each of two positions for each line-pair, as used in the greater part of the present work.
- σ_{T_1}, σ_{T_9} correspondingly apply to single readings from each line-pair and to means of nine readings, respectively.
- σ_{TM} is used in the case of results based on the means of the three upper and three lower readings taken from each line-pair in the deduction of σ_T, and involving, therefore, a reduction in contribution by the photographic plate by the measurement of twice the normal area.
- σ_{TC}, σ_{TMC} correspond to σ_T and σ_{TM}, but with deductions to remove estimated residual microphotometry contributions.

Plate Variability

The standard deviations under this heading refer to the small-scale variability as between independent segments from individual lines. It is indicated by the suffix *P*.

- σ_P is based on differences between two independent 0·5-mm. lengths from the 1·7-mm. lines used, the means of three readings being used.
- σ_{P_9} corresponds to σ_P, but is based on means of nine readings.
- σ_{PC} includes correction for estimated residual reading error in σ_P.
- $\sigma_{P.MC}$ is indirectly deduced from σ_{TMC} to indicate the value of σ_{PC} for 1-mm. segments.

"Sparking" Response Variability

This includes, besides the variability introduced by the excitation procedure, any contributions from sample heterogeneity and large-scale plate variability not covered by σ_{PC}. It is indicated by the suffix *S*.

- σ_{SC} is the only symbol used in this connection and represents the difference between σ_{TC} and σ_{PC}.

Microphotometry

Several standard deviations have been employed to cover total and residual microphotometry (reading) errors included in various other deviations. They are denoted by the suffix *R*.

- σ_R is calculated from the differences between individual readings and the means of three readings for a single line-pair.
- σ_{R_9} is similar, but based on nine repeat readings.
- σ_{RT} is the estimated residual microphotometry error included in σ_T due to reading inaccuracy remaining in the means of three readings used to deduce σ_T.
- σ_{RTM} corresponds to σ_{RT}, but relates to the means of upper and lower readings used for calculation of σ_{TM}.
- σ_{RP} is the estimated residual reading error included in σ_P.

ADDENDUM

Since the preparation of the above paper for publication, the authors have submitted the following note, suggesting that it may be of interest to indicate the values σ_{SC} obtained under the authors' conditions for the actual pair used by Vincent and Sawyer.

In addition to the data presented in Table X, the authors have carried out corresponding readings for the line-pair used by Vincent and Sawyer, *viz.*, Cr 2822·01 and Fe 2811·27.*

The results are of interest in view of the comparison made between the authors' results and those of the American workers. They are, in the order of presentation of Table X:

$\frac{\text{Cr } 2822{\cdot}01 - }{\text{Fe } 2811{\cdot}27\ \text{II}}$	$\frac{34}{35}$	4·5	0·0026	0·0032	0·0033	0·0030

These figures are based on single readings, as for the Fe line-pairs and the Cr(II)–Fe(II) pair in Table X. Based on the means of three readings, the value obtained for plate *RXB*329 remained at 0·0026.

* According to Harrison, the iron line is of the singly ionized type (II) but the chromium line is not classified.

A Comparison of Moulds of Standard Composition

AND OF APPROXIMATELY INGOT MOULD SUB-COMMITTEE COMPOSITION*

By W. L. Kerlie, B.Sc.†

SYNOPSIS

A number of ingot moulds representing two different compositions have been examined under carefully controlled conditions.

Direct correlations between silicon content and mould life and phosphorus content and mould life were found, when all the moulds other than the abnormal ones were considered.

The most important conclusion obtained was that with a mould composition close to the one recommended by the Ingot Mould Sub-Committee an average mould life of 130 casts is to be expected, compared with an average of 100 for the standard composition.

INTRODUCTION

IN the first instance the experiment was designed as a comparison of the lives of the moulds using (1) works standard composition and (2) a composition suggested by the Ingot Moulds Sub-Committee from the results of earlier work‡, of the following analysis :

Total Carbon, %	Si, %	S, %	P, %	Mn, %
Approaching 4	1–1·25	Approx. 0·06	Approx. 0·25	0·8–1·0%

It was found, however, that the analyses obtained were not sufficiently close to the I.M.S.C. composition, particularly in regard to silicon and phosphorus content.

EXPERIMENTAL PROCEDURE

In all, 64 moulds (representing 32 of each type) were examined, and 5 moulds of each type were used during a given period until thrown out, at which stage a further 5 moulds of each type were put into operation. The experimental work was started during the war years, when labour shortage was acute, and it was considered that by operating the moulds in the manner described, the effects of such variations as mould temperature and steel temperature would largely average themselves out, and the recording in the pit would be simplified.

In Figs. 1 and 2 the frequency of operation under typical and abnormal operating conditions is shown. In the latter case, the results apply only to the last two experimental sets. It is quite obvious, however, that, although there are six occasions on which moulds have been used twice within a period of 8 hours, the frequency of operation is reasonably good.

The following conditions obtained throughout :

Type of Mould—Corrugated, 25 in. square bottom, 22⅝ in. square top ; mould weight, 4·2 tons ; ingot weight, 4–4·25 tons.

Steel Used—Basic Bessemer rimming steel (0·04–0·06% carbon).

Teeming—Direct ; 3 ft./min.

THE INFLUENCE OF COMPOSITION ON LIFE

The results obtained in the investigations are shown in Tables I and II. Table I shows that the performance of the standard moulds is a little below that of the moulds of approximately I.M.S.C. composition. The averaged figures for the two groups of five moulds in each period have been examined statistically, omitting the abnormal moulds marked with asterisks in Table I, and the difference between the standard and approximately I.M.S.C. composition moulds has been confirmed as a real effect. (*See* section on "Seasonal Effect.") The summary of results given in Table III shows this up clearly, and indicates also that the proportion of moulds failing by cracking and by crazing is approximately the same for both compositions.

‡ R. H. MYERS : *Journal of the Iron and Steel Institute*, 1943, No. I, p. 51P.

* Paper SM/BA/3/46 of the Steelmaking Division of the British Iron and Steel Research Association, received June 16th, 1947. Published by authority of the Ingot Mould Sub-Committee. The views expressed are the author's and are not necessarily endorsed by the Sub-Committee as a whole.

† Messrs. Stewarts and Lloyds, Ltd., Corby.

TABLE I—*Behaviour of Moulds in Service*

Standard Composition					Approximately I.M.S.C. Composition				Difference in Average Mould Life (I.M.S.C. −Standard).
Period	Mould No.	Weeks in Operation	Life	Mode of Failure	Mould No.	Weeks in Operation	Life	Mode of Failure	
Aug.	*STN*.873	14½	104	VC	*HN* 4	12½	103	VC	
to	906	14	96	VC	5	15½	124	CZ	
Nov.	919	15½	110	CZ	6	17½	133	,,	
1943	921	13	99	VC	7	15½	128	VCs and CZ	
	922	16	112	CZ	8	15½	119	,,	
			104	Average			121	Average	+17
Nov.	*STN*.960	14	108	VC and CZ	*HN* 24	16	124	VC and CZ	
1943	961	16	128	VC	58	17	132	VC	
to	964	16	124	VC	60	16	124	,,	
Mar.	965	17	125	CZ	61	17	136	CZ	
1944	967	16	128	VC and CZ	64	17	125	,,	
			123	Average			128	Average	+ 5
Mar.					*HN* 2	13	97	VCs and CZ	
to					13	11	*** 80*	VC and wear	
June					25	12	90	VC	
1944					35	16	115	CZ	
					66	12	87	VC	
							97 (94 incl.	Average ***)	
July	*HN* 71	11	*** 86**		*HN* 79	13½	108	VC and CZ	
to	72	13½	109	CZ	80	13½	93	CZ	
Oct.							101	Average	
1944	*STN*.1156	13	83	VC and CZ					
	1158	13	70	CZ					
	1159	9½	*** 57**	VC					
	1160	13	*** 65**	VC					
	1163	14	*** 62**	VC					
			87 (67 incl.	Average ***)					+14
Oct.	*STN*. 604	11½	71	VC and CZ	*HN* 1	12½	91	VC and CZ	
1944	675	12	85	,,	11	12½	97	,,	
to	677	14	91	,,	15	12	83	VCs and CZ	
Jan.	1280	13	86	,,	19	6½	*** 50	Broken lugs	
1945	1299	19	100	VCs	22	12½	96	VC and CZ	
			87	Average			92	Average	+ 5
Feb.	*STN*.1365	21	131	VC and CZ	*HN* 38	20	129	VC and CZ	
to	1383	15	101	VC	46	20	129	VCs	
July	1384	15	98	VC	47	21	138	VCs and CZ	
1945	1393	18	110	VCs and CZ	49	21	132	VC and CZ	
	1430	19	123	VCs and CZ	50	22	122	VCs	
			113	Average			130	Average	+17
July	*STN*.1470	18	131	VC and CZ	*HN* 16	14	107	VC and CZ	
to	1524	13	97	VC and CZ	18	12	98	VCs	
Oct.	1525	12	79	VCs	20	11	84	VCs and CZ	
1945	1544	14	109	VCs	21	13	105	VCs	
	1548	15	100	VC and CZ	27	14	110	VCs and CZ	
			103	Average			101	Average	− 2

Mean difference = +93

Notes: VC = Vertical crack
VCs = Vertical cracks
CZ = Crazing

* Wear at bottom edge a cause of failure
** Appearance suggested that steel had been teemed against the mould side, causing early failure
*** Omitted from analysis

TABLE II—*Effect of Composition on Mould Life*

Standard Composition							Approximate I.M.S.C. Composition						
Mould No.	Life	Analysis					Mould No.	Life	Analysis				
		T.C., %	Si, %	S, %	P, %	Mn, %			T.C., %	Si, %	S, %	P, %	Mn, %
873	104	3·72	1·13	0·072	0·094	0·58	4	103	3·46	1·35	0·076	0·20	0·74
906	96	3·82	1·40	0·076	0·084	0·53	5	124	3·76	1·26	0·066	0·15	0·78
919	110	3·72	1·87	0·070	0·080	0·58	6	133	3·68	1·26	0·076	0·19	0·74
921	99	3·74	2·15	0·072	0·084	0·61	7	128	3·61	1·40	0·078	0·31	0·78
922	112	3·65	1·68	0·076	0·088	0·66	8	119	3·44	1·31	0·086	0·26	0·64
960	108	3·55	1·21	0·116	0·060	0·56	24	124	3·55	1·45	0·068	0·16	0·76
961	128	3·44	1·17	0·110	0·064	0·50	58	132	3·55	1·40	0·082	0·14	0·71
964	124	3·46	1·26	0·108	0·066	0·52	60	124	3·57	1·35	0·088	0·16	0·54
965	125	3·49	1·45	0·106	0·079	0·52	61	136	3·41	1·31	0·092	0·16	0·64
967	128	3·34	1·26	0·124	0·076	0·48	64	125	3·35	1·35	0·094	0·21	0·66
71**	86	3·43	1·59	0·072	0·068	0·70	79	108	3·39	1·49	0·086	0·22	0·60
72	109	3·57	1·35	0·072	0·066	0·66	80	93	3·45	1·54	0·068	0·19	0·72
1156	83	3·44	1·68	0·068	0·056	0·76	2	97	3·63	1·45	0·074	0·19	0·86
1158	70	3·41	1·49	0·070	0·058	0·80	13*	80	3·57	1·72	0·084	0·21	0·78
1159**	57	3·44	1·68	0·068	0·056	0·76	25	90	3·33	1·63	0·100	0·16	0·76
1160**	65	3·44	1·77	0·078	0·058	0·74	35	115	3·55	1·49	0·086	0·20	0·88
1163**	62	3·30	1·54	0·078	0·066	0·64	66	87	3·49	1·72	0·096	0·18	0·76
604	71	3·87	1·60	0·062	0·064	0·65	1	91	3·53	1·49	0·058	0·163	0·92
675	85	3·75	1·35	0·054	0·078	0·68	11	97	3·38	1·59	0·078	0·32	0·58
677	91	3·81	1·26	0·060	0·081	0·66	15	83	3·44	1·54	0·080	0·182	0·82
1280	86	3·44	1·45	0·068	0·066	0·54	19***	50	3·52	1·68	0·072	0·21	0·94
1299	100	3·55	1·35	0·104	0·076	0·50	22	96	3·60	1·49	0·088	0·17	0·70
1365	131	3·35	1·31	0·066	0·070	0·56	38	129	3·35	1·45	0·084	0·20	0·76
1383	101	3·46	1·40	0·064	0·060	0·60	46	129	3·66	1·40	0·072	0·146	0·84
1384	98	3·27	1·35	0·068	0·066	0·54	47	138	3·55	1·26	0·096	0·101	0·78
1393	110	3·49	1·31	0·090	0·074	0·58	49	132	3·37	1·35	0·102	0·17	0·42
1430	123	3·42	1·49	0·090	0·060	0·54	50	122	3·41	1·35	0·096	0·17	0·66
1470	131	3·56	1·45	0·064	0·104	0·50	16	107	3·33	1·77	0·078	0·184	0·68
1524	97	3·71	1·68	0·088	0·070	0·58	18	98	3·33	1·72	0·090	0·18	0.68
1525	79	3·53	1·31	0·104	0·080	0·58	20	84	3·65	1·26	0·060	0·18	0·72
1544	109	3·60	1·21	0·064	0·104	0·52	21	105	3·65	1·26	0·060	0·18	0·72
1548	100	3·68	1·26	0·110	0·096	0·60	27	110	3·60	1·54	0·090	0·16	0·80
Averages	99	3·55	1·45	0·081	0·073	0·60		109	3·50	1·45	0·081	0·19	0·73
Averages†	104	3·57	1·42	0·082	0·075	0·59		112	3·50	1·44	0·081	0·19	0·72

† Omitting abnormal moulds marked with asterisks

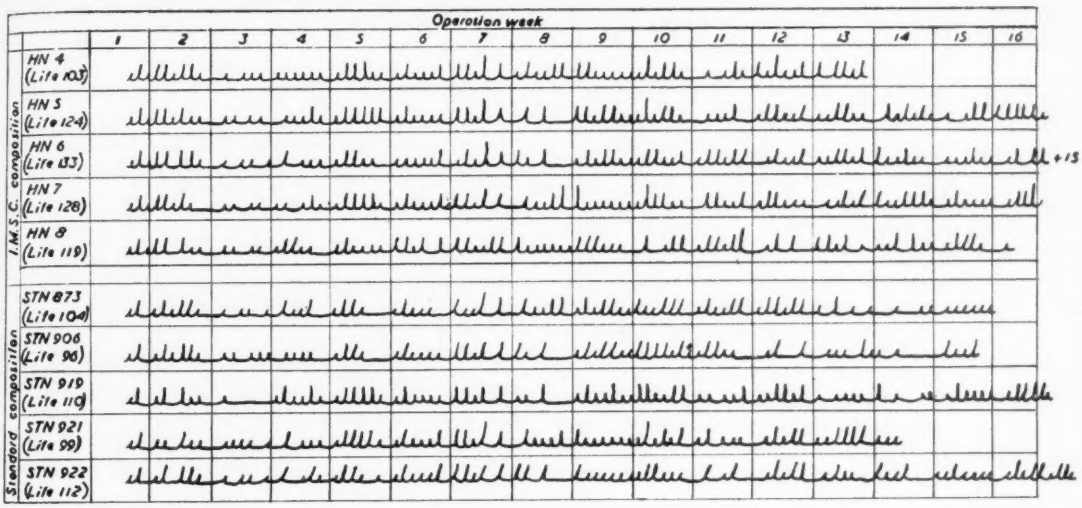

Operation week
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
I.M.S.C. composition
HN 4 (Life 103)
HN 5 (Life 124)
HN 6 (Life 133)
HN 7 (Life 128)
HN 8 (Life 119)
Standard composition
STN 873 (Life 104)
STN 906 (Life 96)
STN 919 (Life 110)
STN 921 (Life 99)
STN 922 (Life 112)

FIG. 1—Comparison of frequency of operation of I.M.S.C. and standard moulds under typical conditions. (A short vertical line represents use once in the 24 hr., a double line twice, etc.)

In Table II, the composition and life of each mould used is given. Plots of silicon content against mould life, based on these results, are shown in Figs. 3 and 4.

Examination of the Data by the Analysis of Variance

Direct correlations between silicon content and mould life, and phosphorus content and mould life, were also made, taking all the moulds (other than the abnormal ones) together, and in each case a significant effect was obtained. Direct correlations are permissible, since there is complete absence of correlation between silicon content and phosphorus content.

An attempt was made to obtain further information from Table II by the use of the analysis of variance. By this means, the effects of two or more factors (*e.g.*, percentage silicon and percentage phosphorus) varying simultaneously can be separately assessed. The method used was that described by K. A. Brownlee.* The figures for the two types of iron were treated separately, with the abnormal moulds omitted.

* "Industrial Experimentation," 1946, pp. 55–63: H.M. Stationery Office.

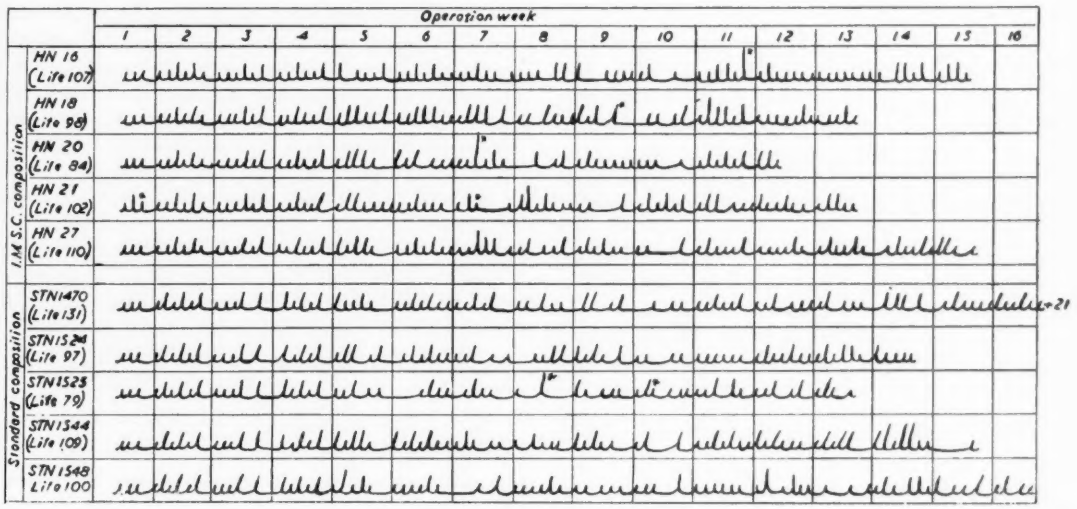

Operation week
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
I.M.S.C. composition
HN 16 (Life 107)
HN 18 (Life 98)
HN 20 (Life 84)
HN 21 (Life 102)
HN 27 (Life 110)
Standard composition
STN1470 (Life 131)
STN1524 (Life 97)
STN1525 (Life 79)
STN1544 (Life 109)
STN1548 (Life 100)

FIG. 2—Comparison of frequency of operation of I.M.S.C. and standard moulds under abnormal conditions. (A short vertical line represents use once in the 24 hr., a double line twice, etc.; * indicates use twice within 8 hr.)

TABLE III—*Summary of Results*

	Standard	I.M.S.C.
Weeks in operation	9½–19	11–22
Mould life*	70–131	83–138
Mode of failure :		
No. by VCs	8 (average life 98)	9 (average life 110)
No. by CZ	5 (,, ,, 105)	6 (,, ,, 121)
No. by VC and CZ	15 (,, ,, 106)	15 (,, ,, 110)
Premature failures	4 (,, ,, 68)	2 (,, ,, 65)

* Neglecting defective moulds or defects brought about by abnormal conditions

Standard Composition

Neither silicon nor phosphorus contents of the moulds of standard composition showed any significant correlation with mould life when the effect of each was examined with the other eliminated.

The effect of total carbon content was also examined, with the effects of silicon and phosphorus contents eliminated. No correlation with mould life was found.

I.M.S.C. Composition

The correlations between silicon, phosphorus, and total carbon contents and life for the moulds of I.M.S.C. composition were as follows :

Silicon (*effect of phosphorus eliminated*)—A negative correlation significant on the high level of 0·1% with a regression coefficient such that an increase of silicon content from say 1·2% to 1·7% decreases the mould life on an average by about 35 casts.

Phosphorus (*effect of silicon eliminated*)—No correlation.

Total Carbon (*effect of silicon eliminated*)—A slight negative correlation, significant only on a 20% level, and therefore not justifying any conclusion.

Inclusion of Data from Abnormal Moulds

If the data from all the moulds except *HN*19 are taken into account, a correlation is found between both silicon and phosphorus content and life for moulds of the standard composition, although the effect of silicon is not very highly significant. The correlations for moulds of the I.M.S.C. composition are unaffected.

If the two sets of results are analysed together by this method, both silicon and phosphorus show marked correlation whether or not the abnormal moulds are included.

The use of the analysis of variance yielded little fresh information, but it has been included because it draws attention to a method which may be useful in similar cases.

Seasonal Effect

The "*t*" test on the difference of 8 in the average life of the two sets of moulds shows that this is only significant on a 10% level. This result, however, is undoubtedly influenced by the general variation of mould life with the period in which the moulds were used. The moulds have therefore been grouped according to period (Table I), and the differences between the averages for each type of mould for each period have been examined.

The mean difference of 9·3 lives can be shown to be quite significant. The standard deviation of the differences is 7·2, and thus the standard deviation of the mean is $7{\cdot}2/\sqrt{6} = 2{\cdot}94$, which is less than $\frac{1}{3}$ of the mean difference, *i.e.*, the

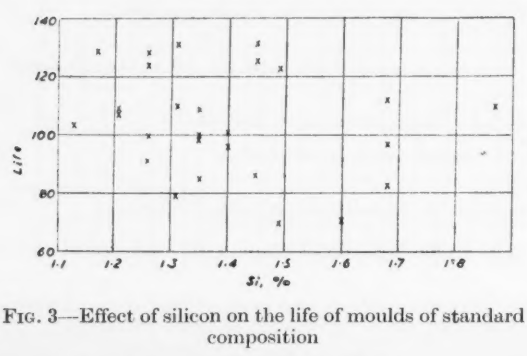


FIG. 3—Effect of silicon on the life of moulds of standard composition

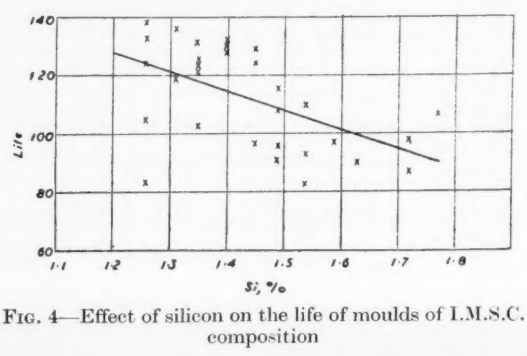


FIG. 4—Effect of silicon on the life of moulds of I.M.S.C. composition

difference is significant on at least the 0·2% level.

It might be argued that the period July to October 1944, should be omitted from this calculation, since it contains fewer moulds of each composition than the other periods. If this is done, the difference in mould lives remains significant on approximately the 1% level.

Conclusions

In general, the following conclusions can be drawn :

(1) For the approximately I.M.S.C. composition mould life increases with decreasing silicon content. The average mould life is above 100 when the silicon content is below 1·5%.

(2) A similar tendency for the standard-composition moulds has not been found to be statistically significant. Further data on this type should prove or discount this possible relationship.

(3) With a mould composition close to the I.M.S.C. recommended composition (*i.e.*, 1·0–1·2% of silicon), an average mould life of 130 is to be expected, compared with an average of 100 for the standard composition (*i.e.*, 1·45% of silicon).

(4) The difference in the phosphorus content between the two compositions (average difference 0·12%) might well be the cause of the small improvement in mould life of 8 lives in favour of the approximate I.M.S.C. composition. The data, when examined as a whole, show that increases in phosphorus content to at least 0·15% increase the expected life of these moulds.

Acknowledgments

The author expresses his thanks to Messrs. Stewarts and Lloyds, Ltd., for permission to publish this work, and his appreciation of the very helpful collaboration of Mr. W. H. Glaisher in the statistical examination of the results.

A Note on Optical Pyrometry*

By Robert Weil, M.Sc., A.Inst.P.†

Synopsis

The effect of the variation with temperature of emissivity is discussed, and it is shown that under certain circumstances it may be possible to express this variation in terms of changes of electrical resistivity also in the near infra-red and visible parts of the spectrum.

Optical pyrometry is based on the knowledge of the emissivity E of a hot body, a narrow wave-band being used. This is usually taken at $\lambda = 0{\cdot}65\,\mu$ (in the red) or, for higher temperatures, at $0{\cdot}55\,\mu$ (green). The accuracy of the temperature measurement depends on the accuracy of the knowledge of the emissivity values, the two being connected by a modification of Wien's formula :

$$\log E = \frac{C_1}{\lambda}\left(\frac{1}{T} - \frac{1}{T_{app.}}\right) \quad \ldots\ldots(1)$$

where C_1 is a fundamental constant, λ the wavelength of the radiation, T the black-body temperature, and $T_{app.}$ the apparent temperature. Since the emissivity E is connected with the reflectivity R of the hot metal by an application of Kirchhoff's law :

$$E + R = 1 \quad \ldots\ldots(2)$$

it would appear that a determination of R should yield a value for E. Some investigators hold, for a variety of reasons, that R can be measured more accurately than E, and thus the indirect measurement of E might have some advantages over the direct determination. This approach to the problem, however, is rendered difficult because R and E are themselves functions of the temperature T. When the temperature variation is unknown, which is the case with many metals, a determination of R at room temperature is pointless if E is to be derived from it for high temperatures. In the visible, as opposed to the infra-red, the temperature variation of these constants is small though not negligible. It would obviously be of some interest to find out whether there is a wavelength for which $\beta\,(=(1/E)/(dE/dT))$ is zero.

Price and Lowery[1] have pointed out that, for a number of metals, such a characteristic wavelength, called the X-point, did in fact exist, and was to be found in the near infra-red. Recently Price[2] put forward a few suggestions to explain the phenomenon. When the present author[3]

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investigated the problem analytically he assumed that only free electrons were involved in the mechanism of emission. Differentiating Fresnel's expression for the reflecting power of an absorbing medium :

$$R = 1 - \frac{4n}{(n+1)^2 + k^2} \quad \ldots\ldots(3)$$

with respect to the temperature T (n being the index of refraction and k the extinction coefficient), and substituting Zener's[4] expressions for n and k, he computed a wavelength for which dE/dT, and thus β, was zero. It was found, however, that this wavelength, in turn, was a function of the temperature. The rigorous expression from which the critical wavelength λ_x is derived is :

$$\left(\frac{2\pi c}{\lambda_x}\right)^6 - \left[2a - \left(\frac{2\pi c}{\lambda_\tau}\right)^2\right]\left(\frac{2\pi c}{\lambda_x}\right)^4 + \tfrac{3}{4}a^2\left(\frac{2\pi c}{\lambda_x}\right)^2 - \frac{a^2}{4}\left(\frac{2\pi c}{\lambda_\tau}\right)^2 = 0 \quad \ldots\ldots(4)$$

where c is the velocity of light, a is a simple function of the number of electrons per cubic centimetre and their charge and mass, and λ_τ is the wavelength corresponding to the time of relaxation of the electrons. The time of relaxation is defined as twice the interval between two electronic collisions. When numerical results are substituted in the above expression it is found that a good approximation is obtained when only the latter two terms are considered. Thus :

$$\lambda_x = \sqrt{3}\ \lambda_\tau \quad \ldots\ldots(5)$$

Since, however, λ_τ is a function of the temperature, λ_x must also depend on it. In fact, since, according to Mott and Jones,[5] the temperature coefficient of λ_τ is equal to that of the electrical resistivity, the latter will also determine the variation of λ_x. Figure 1 illustrates how the emissivity will vary with both wavelength and temperature on the basis of the above free-electron theory. It can be seen that the X-point as envisaged by Price and Lowery is a limiting case of the above, and arises when the temperature variation of λ_τ is zero. It seems doubtful whether the X-points given by Price for several metals have any real meaning. It would appear that they were derived by averaging the results obtained by different workers at high temperatures to give a curve corresponding to T_4 in Fig. 1, and similarly combining reflectivity measurements at room temperature to give a curve T_1. The intersection of the two was said to give the X-point and was assumed to be independent of the temperature. Had the average of the high-temperature results come to lie along T_3, a different X-point would have been obtained.

Admittedly, the presence of absorption bands in the metal in the neighbourhood of λ_τ will have an effect on λ_x which cannot yet be predicted theoretically. It is conceivable that a fortuitous combination of the effects of free and bound electrons may make λ_x constant over large temperature ranges. There is reason to believe that, in the case of steel, in general, λ_x is in the near infra-red and that its temperature variation is comparatively small. The latter can be predicted from resistivity measurements if the effect of the absorption bands due to the bound electrons in the metal can be ascertained. This can be done by catoptric measurements, and it is proposed to examine various kinds of steel for this purpose. If it should be found that the bands are sufficiently far in the ultra-violet, then it is likely that equation (5) will be valid, λ_τ being determinable from such measurements. It follows that the correction factors necessitated by the temperature variation of emissivity could then be predicted ; the benefits accruing from this to the pyrometry of steel are thus manifest.

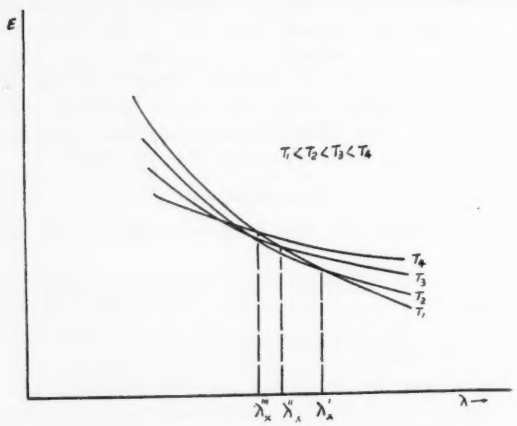

FIG. 1—Variation of emissivity with wavelength and temperature on the basis of the free-electron theory

ACKNOWLEDGMENT

The analysis which led to this note was carried out in connection with the work undertaken by the author under the direction of Dr. H. Lowery, F.Inst.P., for the Pyrometry Sub-Committee of the Steelmaking Division of the British Iron and Steel Research Association.

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BACK-PULL WIRE DRAWING

A Critical Review of Literature*

By J. G. Wistreich, M.Sc. (Eng.), D.I.C.†

SYNOPSIS

The paper is an instalment of a critical survey of literature on wire drawing and is intended to explain the salient features of drawing with back pull and to provide a a basis for further research. For this reason neither patents nor existing machine designs are considered.

In reviewing published papers emphasis has been laid on results bearing on the practice of drawing with back pull, i.e., on the effect of the latter on forces, power consumption, die wear, and on the properties of wire. It is found that the application of back pull brings about a reduction in the die load and—with the aid of a suitable design of the drawing machine—in the power consumption. The literature on the effect of back pull on the mechanical properties of the wire is not conclusive; on the whole, back pull does not appreciably influence the quality of wire as gauged by conventional tests.

INTRODUCTION

In wire drawing the metal is made to flow by a tensile stress due to the drawing force, together with compressive stresses caused by the nip of the die. When back pull is applied, the metal will flow under lower compressive stresses, because the tensile stress has increased. With reduced compressive stresses the force required to overcome friction in the die will be less; consequently drawing with back pull is in itself a more efficient process, a smaller proportion of energy being dissipated by friction.

Since the drawing force must overcome the back pull as well as the load on the die, it is larger than in conventional drawing. The energy consumed by the back pull need not, however, be wasted: by suitable means it can be made to contribute to the work of drawing. Indeed, provided that a sufficiently high proportion of the back-pull energy is recovered, the net power consumption will be less than in conventional drawing.

The back pull cannot be increased beyond a certain limit, which is reached when the tensile stress due to the drawing force equals the tensile strength of the wire at the die exit. This limit varies greatly with drawing conditions and constitutes the most important factor in weighing up the relative advantages of the application of back pull. The limiting ratio of the back pull to the drawing force is greatest for soft materials undergoing light reductions; it is less for hard materials or materials originally soft, but hardened as a result of previous cold working; it also decreases with increasing reduction in the pass.

There is a characteristic factor b in back-pull drawing which, within the limits imposed by the maximum back pull, determines the relative advantages to be gained by applying back pull. The factor is found to be constant for a particular set of drawing conditions, but varies as these change. It increases considerably with increasing reductions, it is higher for hard materials, and probably increases for the same material with increasing cold work. The analysis of the mechanics of back-pull drawing shows that a high factor b means:

(i) For a given back pull, a greater reduction of die load and therefore of the die stresses, resulting in a smaller elastic expansion of the die, in a smaller temperature rise, and in a reduction of friction losses, etc.; a smaller increase in the drawing force.

* Paper MW/D/8/47, submitted by the Drawing Committee of the Mechanical Working Division of the British Iron and Steel Research Association. Received 20th June, 1946. The views expressed in the paper are the author's and are not necessarily endorsed by the Committee as a whole.

† The British Iron and Steel Research Association.

(ii) A lower critical efficiency of drag energy recovery, which must be exceeded in order to effect a saving in power consumption ; for a particular recovery mechanism this means a larger saving of power.

With two exceptions,[3,5] (*cf.* pp. 425 and 426), experiments seem to indicate that back pull does not appreciably affect the mechanical properties of drawn wire.

When applying the above findings to existing practice, the following facts emerge :

(1) The main advantage of back-pull drawing lies with the decrease in the die stress, and therefore with the increase in die life. The saving in power consumption will, on the whole, be small.

(2) Conditions for back-pull drawing are most favourable on the first hole. The motors driving the intermediate blocks of a multihole machine can be made smaller than for conventional drawing, as the blocks provide only the difference between the drawing force and the back pull of neighbouring holes. For maximum overall efficiency the swift ought to be braked and its drag energy recovered and fed back into the power supply.

Whilst on the above reckoning the merits of back-pull drawing may not seem to be economically significant, it should be appreciated that the lowering of die load may bring about many modifications of the drawing process of great advantage, be it through the introduction of better lubricants, better control of the finishing gauge, higher speeds, or heavier reductions (particularly in the wet drawing process), etc.

Historical Notes

Back pull has long been used in the drawing mill* to produce *ad hoc* improvements, but not until comparatively recently was it realized that back pull would reduce the load on the die, and that by a suitable design of the drawing machine it might bring about a saving in power consumption. The Germans claim the first patent (B. Weissenberg and E. Siebel, 15 XII, 1926, DRP 438275),[1] but the first reported experiments on drawing with back pull were made in this country.

F. C. Thompson[2] drew mild steel and 7% nickel-silver wire with a reduction of approximately 20%, applying back pull by means of a weight attached to the free end of the wire, which was passed over a pulley ; the speed of drawing was 0·06 and 3·22 in./min. He found that as the weight was increased, the load on the die decreased, while the drawing force (equal to the sum of back pull and die load) increased. The variation was linear, so that it could be represented by a formula of the type :

$$P = x + yQ$$

where P is the drawing force, Q the back pull, and x and y constants characteristic of experimental conditions. Thompson[2] found that by sufficiently increasing the back pull he could reduce the die load to such a small value that the die could actually be pushed along the wire by hand ; before, however, the die load vanished altogether, the drawing force would attain a value causing fracture of the wire at the die exit.

At about the same time experiments[3] were carried out at the Research Department for the Cold-Working of Steel and other Ferrous Metals of the Sheffield University, with a view to ascertaining the effect of drawing with back pull on the properties of drawn wire. The wire and die were placed in a tensile testing machine with a dead weight on the die ; the wire was then tensioned until drawing occurred for the given die loading. It was found, on comparing the wire thus drawn with the same wire drawn conventionally (*i.e.*, without back pull) that, whilst there was no significant change in the tensile strength of the wire, the reduction of area in the tensile test was less for the wire drawn with back pull and became alarmingly low for large drawing reductions.

The British work roused interest in the U.S.A., where several workers[4, 5, 6, 7] carried out experiments, and patents were filed for machines employing back pull. American experiments confirmed Thompson's findings and also the Sheffield results for the ultimate tensile stress ; other tests of the properties of the drawn wire were also recorded, *e.g.*, the number of torsions and reversed bends to produce fracture, and the variation of hardness across the wire section. Furthermore, the power consumption was estimated or measured, and was found to be less than for conventional drawing.

The work was taken up during the last war by W. Lueg and A. Pomp[1, 8] in Germany, where a new patent for a machine employing back pull was filed by H. Muecke (DRP 717253, 9/2/1942). Lueg and Pomp, besides repeating experiments carried out by earlier workers, measured the diameter and temperature of the wire leaving the die, and found—as was to be expected—that both decreased with the application of back pull. The reduced normal stresses in the die and larger longitudinal stresses in the wire meant less elastic expansion of the die and therefore the effective diameter of the hole was smaller, whilst the

* *Cf.* letter to Editor in *Wire Industry*, 1945, vol. 12, p. 193. The writer used back pull in 1916 when drawing 0·6–0·7% C steel, 14 S.W.G. square wire, and in 1918 for finishing drafts on high-tensile wire. The back pull was applied by running the wire round 2 wooden pegs before leading it into the die. The object was to ensure a smooth feed into the die by slightly tensioning the wire.

decrease in temperature was due to less friction energy being generated in the die.

Drawing with back pull has been advocated for many years by K. B. Lewis in America. More recently, attention was drawn to it in this country by the publication of a series of condensed reprints[9] of original papers. An attempt at a correlation of results was made by Howden and Lunt[10] with a view to assessing the effect of back pull on die wear and die life. Most recently Lunt and MacLellan considered back pull in their paper on the theory of drawing.[11]

List of Symbols

A = Cross-sectional area of the wire (sq. in.)
b = Back-pull factor—rate of decrease of die load with back pull
F = Die load (lb.)
f = Die-life factor—F_0/F
L = Length of wire (in.)
P = Drawing force (lb.)
Q = Back pull (lb.)
q = Back-pull ratio—(Q/P)
r = Reduction in area by drawing through die—$\left(1 - \frac{A_2}{A_1}\right)$
W = Net energy input per unit volume of wire (lb./sq. in.)
w = The ratio of energy inputs for drawing with and without back pull—$(w = W/W_0)$
α = Half angle of die cone
ρ = Drag-energy recovery factor (fraction of back-pull energy usefully employed)
ρ_{crit} = Drag-energy recovery factor for which the net energy input when drawing with back pull is equal to the energy consumed in drawing without back pull.
UT = Ultimate tensile stress (lb./sq. in.)

Suffixes

0.....Refers to conventional drawing (*i.e.*, without back pull)
1, 2.....Conditions at die entry and exit respectively

I—The Mechanics of Back-Pull Drawing

It follows from Fig. 1 that, with the notation adopted,

$$P = F + Q \quad \text{.....(1)}$$

and, naturally, in conventional drawing (since $Q = 0$)

$$P_0 = F_0 \quad \text{.....(2)}$$

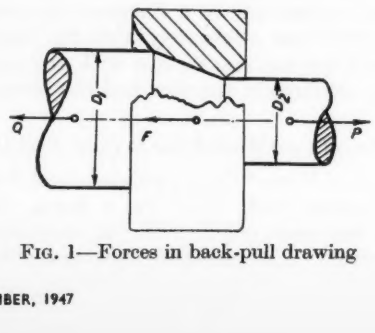

Fig. 1—Forces in back-pull drawing

As already mentioned, Thompson established that a simple linear relationship existed between the load on the die and the back pull, namely :

$$F = F_0 - bQ \quad \text{.....(3)}$$

where b, the back-pull factor, was constant for given experimental conditions and less than unity. It follows from equations (1) and (2) that :

$$P = P_0 + (1 - b)Q \quad \text{.....(4)}$$

It follows from Thompson's equations that, as back pull is applied, the die load falls and the drawing force increases.

The Maximum Back Pull

The amount by which a wire can be reduced in the die is, in the first place, limited by the tensile stress due to the drawing force to which the wire is subjected at the die exit and which it can safely carry. The wire will break when the stress exceeds its ultimate stress, and in practice the stress must be well below the strength of the wire in order to safeguard against a possible temporary increase in the drawing force P, or a local lowering of the ultimate stress.

In conventional drawing scoring, overheating, or even bursting of the die may occur well before P attains this critical value ; in back-pull drawing, on the other hand, the tensile stress in the wire will be the sole criterion, because the die operates under less stringent conditions. Since the drawing force increases with back pull, it is important to know the maximum back pull that can be safely applied.

Experimental results show that this varies greatly with the reduction and with the amount of previous cold work. With the back pull that causes fracture expressed as a percentage of the corresponding drawing force, representative figures are :

Patented (0·58% C) steel, single drafts (Lueg and Pomp)
95% back pull for 10% reduction
53% „ „ „ 44% „

Low-carbon rod, multihole drafts with 36% reduction per pass (Lueg and Pomp[8])
62·5% back pull in 1st pass
49·5% „ „ „ 2nd „

*Copper, in 6 holes, no back pull in 1st, with 20% reduction per pass throughout (Mueller[4])**
73% back pull in 2nd pass
62% „ „ „ 5th and 6th pass

Lueg and Pomp's results for single holing are plotted in Fig. 2, from data given in Table II.

The following formula may be used to calculate the maximum safe back pull, when the back-pull factor and the drawing force in conventional drawing are known.

* These values of back pull did not cause fracture.

Let s be the factor of safety determined by practice, such that :

$$P_{o(max)} = sA_2UT_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Then from equation (4), since UT_2 is not affected by back pull (*cf.* Part II) :

$$Q_{(max)} = \frac{1}{1-b}\left(sA_2\,UT_2 - P_o\right) \quad \ldots\ldots\ldots\ldots (6)$$

The value of $Q_{(max)}$ may well be found to be so small for some drawing processes, that back-pull drawing will not be worth providing for ; in any event this limitation must be kept in mind when assessing the results outlined below. In particular, it should be noted that the same conditions which produce a high value of b also reduce the limiting back-pull ratio $q_{(max)}$.

The Back-Pull Factor

It will be shown below that the value of the back-pull factor is of paramount importance in the process of back-pull drawing, that all calculations for the efficient planning of the drawing process require a knowledge of it, and that it largely determines the economic advantages of back-pull drawing. It is therefore of greatest interest to find what are the factors affecting the value of b and what is the nature of their influence.

Back-pull factors were calculated from all published results by Howden and Lunt,[10] and are reproduced in Table II. An attempt has been made to separate the effects of experimental variables on the value of b, and an analysis is given below.

Constancy of Back-Pull Factor

While most writers dismiss small departures from a straight-line relationship, Stringfellow[7] thinks that it cannot be credited entirely to experimental error. He quotes experimental results which show a considerable change in the back-pull factor ; these are given in Table I.

TABLE I—*Stringfellow's Back-Pull Factor*

$\frac{Q}{F_o}$	12·5%	37·5%	100%
$\frac{F_o - F}{F_o}$	12·5%	28·75%	60%
k	1·00	0·77	0·60

He argues that as the back pull is increased, the stress system changes in such a way that a growing number of the available crystal slip planes is used up, with a resulting change in the mean value of the yield stress, so that b will vary with Q.

The matter is effectively dealt with in Heselwood's experiments.[12] Four materials were tested, each under seven conditions of back pull (ranging from 0 to 60 lb.), with 6 individual tests for each set of conditions, made on completely separate and random occasions. Mean die loads were computed by statistical methods, together with the 1 in 20 limit of accuracy for the mean values. When these results were plotted against the back pull, straight-line relationships fitted all the experimental results.

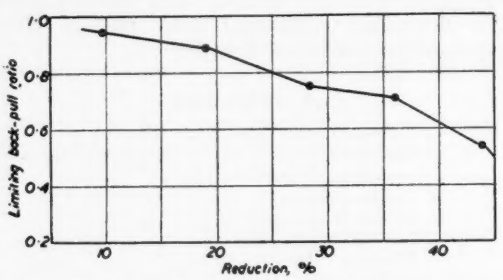

FIG. 2—The effect of reduction on the limiting back-pull ratio based on Lueg and Pomp's single-hole tests

The Effect of Material

The back-pull factor varies considerably with the material of the wire. Heselwood[12] drew wires of 4 different materials through the same die with the same lubricant, speed, and reductions. The results are collected in Table III.

More results are obviously needed to establish the manner of dependence of b on the material ; it may, however, be expected that b will vary with the carbon content of carbon steels.

The Effect of Reduction

Lueg and Pomp[8] carried out single draft experiments with the material, die angle, lubricant, and drawing speed remaining the same, whilst varying the reduction. The results are plotted in Fig. 3 and given in Table IV ; they show a considerable increase of b with r. The relationship is practically linear and can be expressed very approximately by the formula $b = 1{\cdot}03r + 0{\cdot}14$. It should be noted, however, that in the first place the values of b were computed from small graphs of P against Q (and there are discrepancies between Howden and Lunt's, and the writer's figures), and secondly that each test was carried out in a different die, and it is not known how accurately the die angle was measured nor can one assume with any certainty that the surfaces of the dies had the same finish.

The Effect of Cold Work Prior to Back-Pull Drawing

Lueg and Pomp[8] drew patented steel wire, and a low-carbon rod, each in 4 holes, through dies of the same angle, with the same lubricant and speeds. Unfortunately the reductions per

TABLE II—*Details of Experiments on Back-Pull Drawing (Quoted from Howden and Lunt's paper)*

Test	1	2	3	4	5	6	7	8	9	10
Investigator ...	Thompson		Lewis	Simons	Heselwood†					
Wire Material ...	Ni–Ag	Mild steel	Mild steel	0·44% C steel	Mild steel	Mild steel	18/8 Stainless steel		High-C steel	13% Cr/ 5·5% Al
Initial Diameter of Wire, in.	0·072	0·072	0·025	0·098	0·040	0·040	0·040	0·040	0·040	0·040
Reduction, % ...	19·9	19·9	22·8	33·3	19·0	19·0	19·0	19·0	19·0	19·0
Die Material ...	Tungsten Carbide									
Die Semi-Angle	5·5	5·5	5·0*	7·0*	6·25*	8·25*	6·25*	8·25*	8·25*	8·25*
Lubricant ...	Soap No. 3535		Soap							
Speed of Drawing	0·005 ft./min.		23·6 ft./min.		2 ft./min.					
P_o, lb.	56·0	59·0	22·1	377·0	48·0	60·0	88·5	121·0	87·0	88·0
Max. Q Applied, lb.	210	176	22·1	500·0	50·0	60·0	50·0	60·0	60·0	60·0
b	0·27	0·31	0·50	0·52	0·45	0·58	0·53	0·72	0·73	0·60
p_{crit}, % ...	...	...	65	72	69	53	55	35	35	51

* With 50% parallel † Quoted from original report

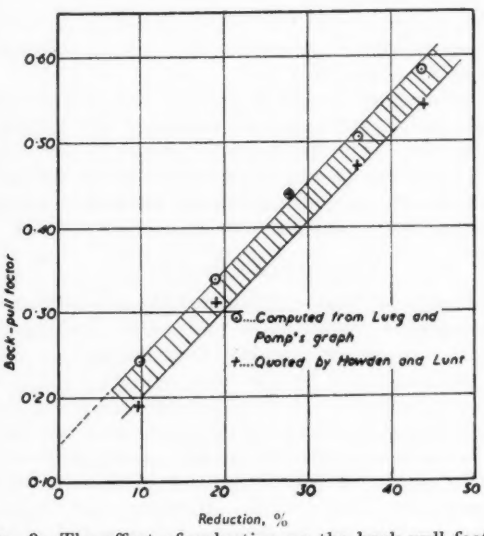

FIG. 3—The effect of reduction on the back-pull factor based on Lueg and Pomp's single-hole tests

hole varied. In order to eliminate the effect of this the values of b for the patented steel wire have been ' corrected ' to a constant reduction per hole, as shown in Table V (a), with the aid of Fig. 3.

The data—excluding the corrected back-pull factors—are quoted from Howden and Lunt.[10]

TABLE III—*The Effect of Material on the Back-Pull Factor*

Test*	Material†	Maximum Stress (UT_1), tons/sq. in.	Hardness‡ (V.D.H.)	b
6	Mild steel	41	192–204	0·58
9	High carbon steel	50	247–264	0·73
8	18/8 Stainless	77	339–352	0·72
10	Red Fox 135§	62	315–331	0·60

* Reference to Table II, which contains other details of tests.

† All wires were in ' light drawn ' condition.

‡ Surface–core.

§ Electrical-resistance 13% Cr–5·5% Al alloy.

TABLE IV—*Lueg and Pomp's Single-Hole Tests*

Patented (0·58% C) steel wire, 4 mm. dia., of approx. 63 tons/sq. in. tensile strength, drawn with a speed of approx. 12 ft./min. through 'Hartmetall G.1' dies of 5·5° semi-angle, the lubricant being 'drawing oil.' The results are computed from the graphs in their paper.

Reduction, %	b	Howard and Lunt's b[10]	$q_{(max)}$	ρ_{crit}*	$F_{(min)}/F_o$*
9·8	0·24	0·19	0·945	0·865	0·214
19·0	0·34	0·31	0·885	0·830	0·278
27·8	0·44	0·435	0·750	0·785	0·358
36·0	0·50	0·47	0·705	0·800	0·450
43·8	0·58	0·54	0·530	0·815	0·615

* Data for Figs. 2, 4, and 6.

It is seen that the variation in b cannot be entirely accounted for by the variation in the reduction per hole, since when allowance is made for this variation the corrected back-pull factor increases with cold work; this is shown in Fig. 4.

The results for the rolled rod, given in Table V (b), show the same tendency if the first hole is excepted. The value for the first hole is, in any case, anomalously high and may well be due to the irregularities in the shape of a rolled rod. Howden and Lunt[10] also quote figures obtained by Stringfellow for two lots of 0·60% C steel wire which were reduced by 27%, presumably in the same die. One length, annealed, and of $UT_1 = 35·6$ tons/sq. in., gave $b = 0·391$; the other, not annealed, and of $UT_1 = 44·5$ tons/sq. in. gave $b = 0·78$.

TABLE V (a)—*Lueg and Pomp's Multihole Tests (Patented steel)*

Pass	Reduction per Hole, %	b	b, Corrected for 30% Reduction per Hole
1	28	0·44	0·46
2	32	0·56	0·54
3	26	0·51	0·56
4	30	0·61	0·61

TABLE V (b)—*Lueg and Pomp's Multihole Tests (Rolled Rod)*

Hole	Reduction per Hole, %	b
1	36	0·74
2	36	0·46
3	34	0·56
4	28	0·46

TABLE V (c)—*Mueller's Experiments on Copper*

Hole	2	3	4	5	6
b	0·49	0·51	0·53	0·49	0·52

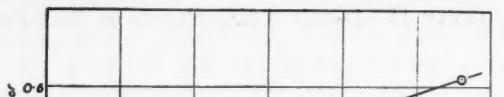

FIG. 4—Lueg and Pomp's multihole tests (corrected to a constant reduction per hole)

The following figures are calculated from results of experiments by Mueller,[4] who drew soft copper wire in 6 holes of 20% reduction in each, first without back pull and then applying large back pulls in all but the first hole. The figures in Table V (c) were calculated with the aid of equation (3).

It may be concluded that b varies with cold work, but that the mode of variation cannot be safely deduced from available experimental evidence.

Other Variables

While no experiments have been made specifically for the purpose of investigating the effect of other drawing variables it is worth noting that Heselwood,[12] in his two sets of experiments, used two dies of different angles for the same materials. Reference to Table II will show that for both mild and stainless steel the back-pull factor increased together with P_o, when the die angle was changed from 12·5° to 16·5°.

To sum up, the back-pull factor is always less than unity, but varies considerably with drawing conditions. The trend of the effects of some of the variables can be discerned from published results but, clearly, considerably more research is needed to establish quantitative relationships.

THE POWER CONSUMPTION

Most investigators tensioned the wire either by attaching a weight to its end, or by braking the swift. In either case the drag energy, *i.e.*, the work performed by the wire against back pull, was dissipated. It was, however, realized that drag energy could be usefully employed, and most patents incorporate devices for 'energy recovery.'

To assess the practical value of these devices, Lueg and Pomp,[8] also Howden and Lunt,[10] compared the two conditions of back-pull drawing, one with full recovery, the other without recovery

of the drag energy, and then set these against conventional drawing. They found that, when all the drag energy is recovered, drawing with back pull uses up less power than does conventional drawing, the saving depending on the amount of back pull applied, on the back-pull factor, and on the reduction.

A full recovery cannot be achieved in practice, and therefore a more sensible undertaking is to derive a general formula which will apply to any fraction of energy recovered. For this purpose the work in drawing a unit volume of wire will be considered for a recovery factor ρ. The net energy input per unit volume is then :

$$W = \frac{PL_2}{A_2L_2} - \rho\frac{QL_1}{A_1L_1} = \frac{P}{A_2} - \rho\frac{Q}{A_1} \quad \text{.....(7)}$$

and for conventional drawing :

$$W_o = \frac{P_oL_2}{A_2L_2} = \frac{P_o}{A_2}; \quad \text{.....(8)}$$

whence the ratio of the two is :

$$w = \frac{E}{E_o} = \frac{P}{P_o}\left[1 - \rho\frac{A_2}{A_1} \times \frac{Q}{P}\right] \quad \text{.....(9)}$$

If now $Q/P = q$, for shortness, then from equation (4) :

$$\frac{P}{P_o} = \frac{1}{1 - (1 - b)q} \quad \text{.....(10)}$$

Substituting this, and also $(1 - r) = A_2/A_1$ into (9) :

$$w = \frac{1 - \rho(1 - r)q}{1 - (1 - b)q}; \quad \text{.....(11)}$$

whence, for $\rho = 0$

$$w_{\rho=0} = \frac{P}{P_o} = \frac{1}{1 - (1 - b)q} \quad \text{.....(12)}$$

and for $\rho = 1$

$$w_{\rho=1} = \frac{1 - (1 - r)q}{1 - (1 - b)q} \quad \text{.....(13)}$$

Equation (13) also represents the ratio of energies stored in the wire, when drawing with and without back pull.

It follows from equation (12), and from the fact that b is always less than unity, that if none of the drag energy is recovered, back-pull drawing must consume more power than conventional drawing. Experiments show (*cf.* Table II) that b is always greater than r ; therefore full recovery guarantees a saving in power consumption (*cf.* equation 13), or in other words back-pull drawing is intrinsically a more efficient process.

The amount of energy saved when a constant fraction of the drag energy is recovered will vary with the back-pull ratio q, as shown in equation (11) and in Table VI.

The figures shown in Table VI are given by Stringfellow.[7]

Mueller[4] drew soft copper wire in 6 holes with 20% reduction in each, and applied back pull in all but the first hole. He calculates the total saving in power as 25% when based on the 6-hole draft, and as 37% when the first hole is disregarded.

TABLE VI—*Reduction in Power Consumption by Recovery of Drag Energy*

r, %	q, %	Reduction in Power Consumption, %
19	31	14–22
	50	34–39
24	31	20
	50	34
27	31	20
	50	30–42
31	31	19
	50	31

As against this, one must set Lueg and Pomp's[8] calculations of the power consumption for a full recovery. They find maximum theoretical savings of 15–30% in single-hole drafts of 10–45% reduction, and a maximum theoretical saving of about 30% when drawing patented steel wire in 4 holes with around 30% reduction in each hole. From these calculations they conclude that the actual saving in power will in practice be insignificant, since a good fraction of the drag energy must needs be wasted in the process of conversion.

It is of interest to determine the critical recovery factor for which the power in back-pull drawing will just equal that in conventional drawing. From equation (11) the condition for $w \gtrless 1$ is :

$$\rho_{crit} \lessgtr \frac{1 - b}{1 - r} \quad \text{.....(14)}$$

This critical value has been calculated for Lueg and Pomp's experiments on single-hole drafting, and is found to be in the region of 80–85%. The point worth noting is that the critical recovery factor does not depend on the back-pull ratio q and that, since experiments seem to suggest that b increases practically linearly with r, the critical recovery factor does not vary greatly with reduction.

Here, as before, a high value of b is beneficial as it gives a low value of ρ_{crit}. This provides the engineer with a wide margin for his design of the drag-energy recovery mechanism, and consequently there is a better chance of effecting a saving in power. Incidentally (as shown in Table II), Stringfellow's values of ρ_{crit} are in the region of 40–60%, which explains why he is more optimistic about power saving than Lueg and Pomp. However, even 80% is not an impossible figure to achieve in practice, although it would be difficult to recover much more than this.

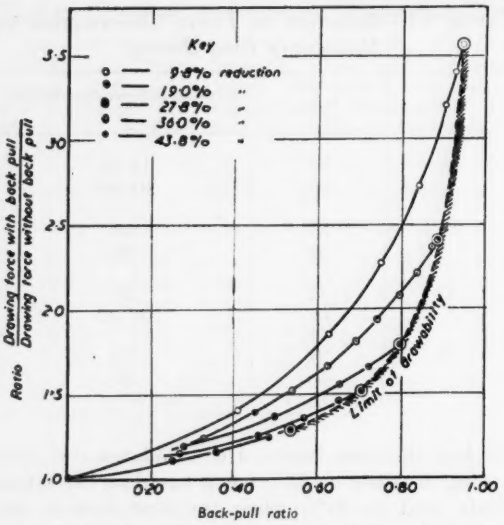

FIG. 5—The effect of reduction on the P/P_0 ratio quoted from Lueg and Pomp's paper[8]

In conclusion, it may be said that it is possible to draw with back pull for the same energy expenditure as in conventional drawing, and with a very efficient recovery mechanism the power required may be less. The critical recovery factor below which back-pull drawing consumes more power, depends only on b and on the reduction, and is low for high values of b. The energy saving depends on b, r, and also on the back-pull ratio (and of course on ρ); this, too, is greatest for high back-pull factors.

Torque Requirements

Since the drawing force increases with back pull, the block must cope with an increased torque. In a multi-block machine the back-pull torque of the succeeding hole can provide a portion of the drawing torque, and then the intermediate motors will be much smaller than in conventional drawing. The last block, however, must carry the full drawing torque, which may be several times as large as in conventional drawing. For this reason the relation between drawing force and back pull ought to be studied.

A graph was plotted by Lueg and Pomp[8] of P/P_0 against q for their single-draft tests on patented steel wire, and is reproduced here (Fig. 5). It shows that the drawing force increases considerably for small reductions, *e.g.*, over 3·5 times for a 10% reduction and a back-pull ratio of 0·9. For large reductions the drawing force is much less sensitive to back pull, *e.g.*, for reductions above 40% the drawing force does not exceed the force in conventional drawing by more than 50%.

The relation between P/P_0 and q is expressed analytically by equation (10). This indicates that the increase of P/P_0 with q depends on the back-pull factor. The figures in Table VII, computed from equation (10), illustrate the advantage of a high back-pull factor.

TABLE VII—*The Effect of b on the P/P_0 Ratio*

b	0.25	0.50	0.75
P/P_0 (for $q = 0·9$)	3·08	1·82	1·29

Die Load

Since the die load decreases with back pull, drawing with back pull brings about a reduction in the pressure on the die wall and therefore in the amount of friction generated. For these reasons the elastic expansion of the die and the rise of temperature in the die are less. How the wear of the die and, therefore, the die life, varies with pressure, temperature, and friction is not known, but it is clear that the rate of die wear will be smaller for lower wall pressures, *i.e.*, for smaller die loads.

By arranging equation (3) thus:

$$-\Delta F = b \Delta Q,$$

it is seen that the amount by which the die load decreases for a given increase in back pull, depends on the back-pull factor, a high value of b being an advantage. This is illustrated by Fig. 6, where F/F_0 is plotted against reduction for constant back-pull ratios (based on Lueg and Pomp's values of b and r). On the other hand, the decrease in die load for a particular drawing operation is limited by the maximum back pull that can be safely applied. That this largely offsets the advantage of a high b, is also shown in Fig. 6 by the curve "limit of drawability," which joins the points of the minimum attainable die loads for various reductions.

Howden and Lunt[10] introduce a "die-life factor" f (equal to F_0/F), and compute it for

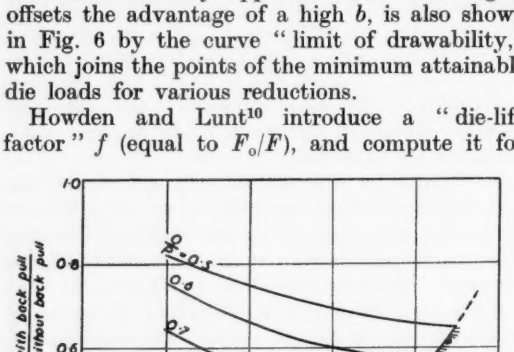

FIG. 6—The effect of back pull on the load based on Lueg and Pomp's single-hole tests

published experimental results. Some of their figures are reproduced in Table VIII, together with the back-pull ratio for which f was calculated.

TABLE VIII—*Howden and Lunt's Die-Life Factor*

Experiment*	Material	r	b	q	f
1	Nickel silver	0·199	0·27	0·99	28·1†
2	Mild steel	0·199	0·31	0·98	9·4†
5	,, ,,	0·190	0·45	0·66	1·8
3	,, ,,	0·228	0·50	0·67	2·0
6	,, ,,	0·190	0·58	0·71	2·5
4	0·44% C steel	0·333	0·52	0·82	3·3
9	High carbon steel	0·190	0·73	0·58	2·0
7	18/8 Stainless steel	0·190	0·53	0·45	1·4
8		0·190	0·72	0·43	1·5
10	Red Fox, 13% Cr/5% Al	0·190	0·60	0·54	1·7

* The numbers refer to Table II, where fuller details of the experiments are given

† For values of q approaching unity a small error in b is multiplied in f many times, therefore these two figures are considerably less accurate than the remainder.

From Table VIII the conclusion is drawn that the highest possible back-pull should be employed in each case in order to derive full benefits. The term " die-life factor "[10] is purposely avoided here, because there is no knowledge of how the die life varies with the die load. This incidentally is a most important item for investigation.

It is clear that, since the resistance to further deformation increases with cold work (*i.e.*, as $A_2UT_2 - P_o$ becomes less), the limiting back-pull ratio falls rapidly with each succeeding pass. Consequently the greatest relative reductions in die stresses are made in the early passes. The following data by Lueg and Pomp[8] bring this out :

(i) Drawing patented steel wire in 4 holes, with approximately the same reduction per hole ; estimated reduction of die stress is 27% when back pull is applied in 2nd, 3rd, and 4th holes, and 46% if back pull is also applied to 1st hole.

(ii) Corresponding figures for a 4-hole draft of a mild-steel rod are 20% and 38%.

Assuming that the relation between die life and stress obeys the same rules as in rolling mills, the authors obtained for the first experiment 2·0- and 4·2-fold increases in the die life, and 2·6- and 6·4-fold increases for the second experiment.

The Effect of Back Pull on Temperature in the Die

It is obvious that diminished friction (due to a decrease in normal stresses on the die wall) means less heat generated ; *i.e.*, in drawing with back pull the die will be cooler. Less heat generated also means a cooler wire surface. Lueg and Pomp record up to 30% drop in the wire surface temperature for large percentage back pulls.

The Effect of Back Pull on the Diameter of the Drawn Wire

The diameter of the drawn wire differs somewhat from the exit diameter of the die hole : the drawing force strains the wire even after it has left the die and the compressive stresses, which help to deform the wire in the die, must also cause an elastic expansion of the die hole. With back pull the compressive stresses are smaller and the drawing force is larger than in conventional drawing. It is to be expected, therefore, that when back pull is applied to a wire drawn through a particular die, the diameter of the finished product will become smaller.

Lueg and Pomp[8] measured the diameter of the drawn wire for various back pulls, and found reductions in it up to 1·5% for back-pull ratios above 50%. They also found that, with greater reductions in the draft, even lower back-pull ratios would cause a perceptible change in the diameter.

II—PHYSICAL PROPERTIES OF THE WIRE

Experimental results are collected in Figs. 7, 8, 9, 10, and 11. No general conclusions can be drawn from these, as the work is fragmentary, and where investigations by two different workers cover the same field, the results are often contradictory.

Tensile Strength

In general it seems that pre-stressing the wire by back pull has no appreciable effect on the ultimate tensile stress. Against Stringfellow's results,[7] reproduced in Figs. 8, 9, 10, which all show a fair increase in the ultimate stress with increased back pull, one has to set the Sheffield results[3] (Fig. 7), which show no difference in the ultimate stress between the wire drawn conventionally and wire drawn with about a 90%-back-pull ratio. The Sheffield results are corroborated by Lueg and Pomp,[8] who drew 0·58%-C steel wire in a 4-hole process with a constant back-pull ratio of 40%. They report that at no point during the drawing process were the tensile strength results influenced by the back pull.

Reduction of Area in Tensile Test

The Sheffield results[3] reproduced in Fig. 7, show an alarming drop in ductility as measured by the reduction of area to fracture for back-pull drawing. No other evidence of this is available.

Bend Test

Lueg and Pomp[8] state that at no point in their

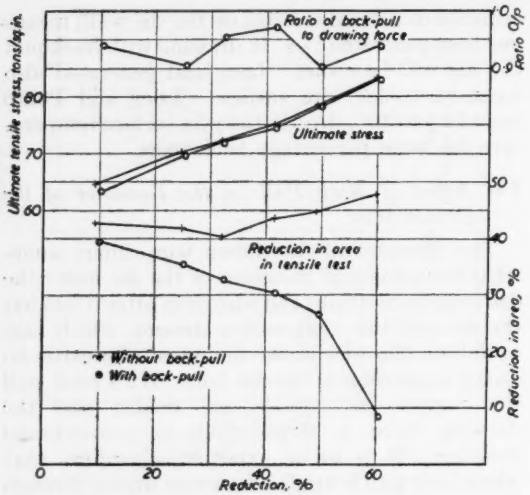

FIG. 7—Effect of back pull on the properties of mild steel wire in multihole drawing (Sheffield University, Research Dept.)

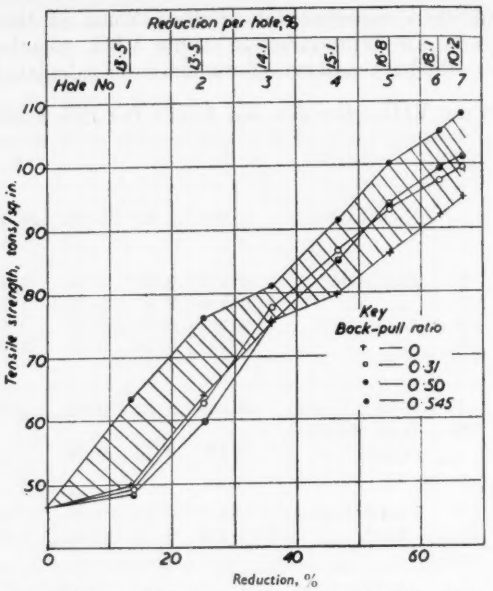

FIG. 8—Effect of back pull on the properties of 18/8 stainless-steel wire in multihole drawing (Stringfellow)

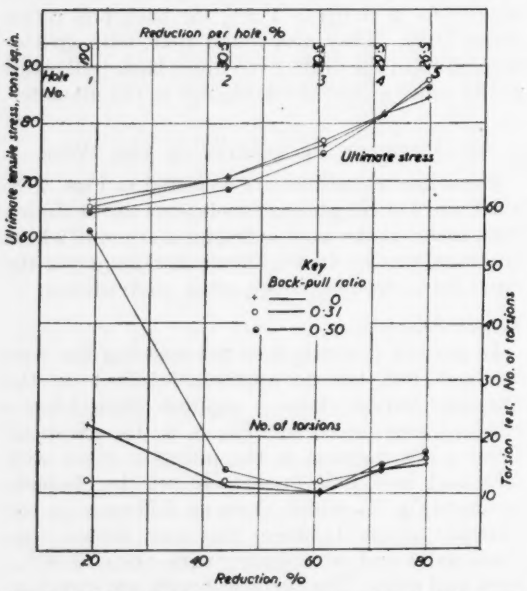

FIG. 9—Effect of back pull on the properties of Cr–V steel wire (for springs) in multihole drawing (Stringfellow)

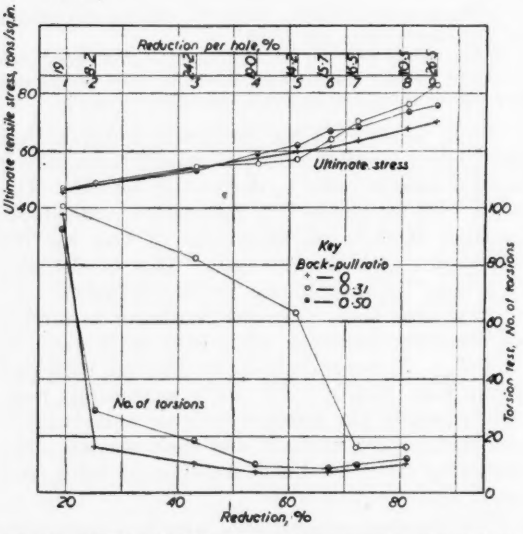

FIG. 10—Effect of back pull on the properties of 0·6% C steel wire in multihole drawing (Stringfellow)

4-hole experiment were the bend-test results influenced by the back pull.

Hardness

Simons[5] examined the variation of hardness across the cross-section of the wire (for details of experimental conditions *see* Table II, Test 4) and found (Fig. 11) that whereas in simple drawing the Vickers hardness decreased from the centre towards the wire surface, the hardness grew more uniform with increasing back pull, and the difference disappeared altogether for $q = 80\%$. These observations were confirmed qualitatively by an X-ray examination (the width of diffraction bands indicating the degree of work-hardening). Thus it would seem that back pull hardens the wire surface.

It is not easy to see why, in conventional drawing, the core of the wire should be harder than its surface. It would seem that the outer layers suffer greater deformation because of their displacement relative to the core, and the sudden

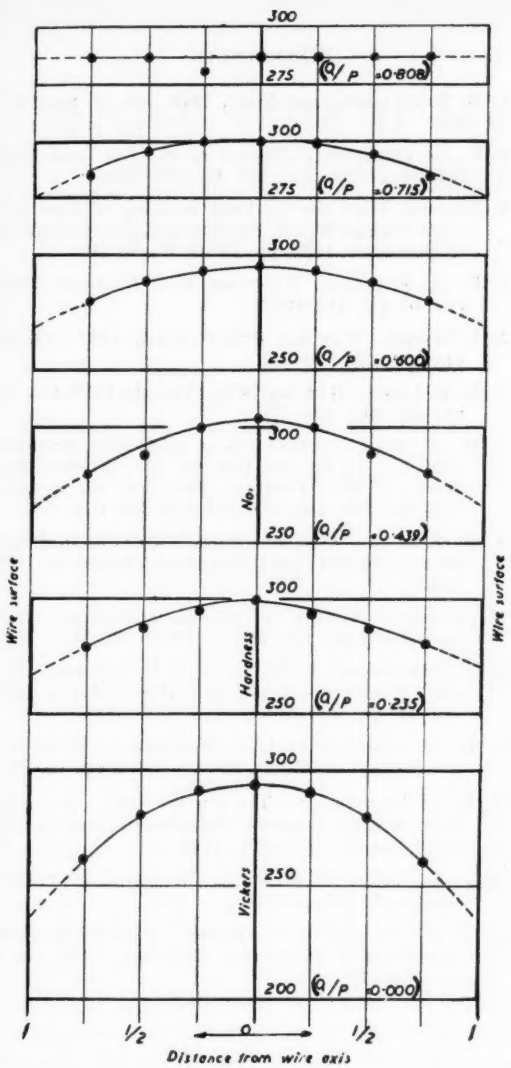

FIG. 11—Effect of back pull on the hardness of patented steel wire across the wire section (Simons)

cooling of the wire surface on leaving the die would also seem to contribute to an increase in hardness. The increase of hardness from surface towards centre of the wire is, however, also reported by G. I. Pogodin-Alexejew[13] and by F. C. Lea and R. A. Batey.[14]

Simons concluded from his findings, that wire drawn with back pull would have a higher resistance to torsion. This is borne out by other experiments.

Torsion Test

Stringfellow's[7] results (*cf.* Figs. 8, 9, and 10) show a slight improvement in the number of torsions with increasing back pull. His results are corroborated by Lueg and Pomp,[8] as shown in Table IX.

TABLE IX—*The Effect of Back Pull on Torsion (Lueg and Pomp)*

Test details : 0·58% C steel wire reduced from 4·0 mm. to 2·0 mm. dia. Number of torsions measured on a test length equal to 100 diameters.

Hole	*r* per Pass	No. of Torsions	
		$q = 0$	$q = 40\%$
1	28	32	32
2	32	46	48
3	26	38	46
4	30	40	49

CONCLUSIONS

An attempt has been made in this review to explain the salient features of back-pull drawing and to discern empirical relations between drawing variables. The effect of back pull on the mechanism of plastic deformation will be dealt with in a review of the theories of wire drawing. It is clear that knowledge to date is too fragmentary for application in drawing practice. It is hoped that the review not only states the need for further investigations, but also indicates the most important lines of research. This should cover, more thoroughly than has been done hitherto, the value of the back-pull factor under diverse drawing conditions, and the effect of back pull on the physical properties of the wire; the relation between die life and die load must also be established. Nevertheless, it must be realized that such investigations can only provide empirical knowledge of a limited character, and nothing but a fundamental approach to the phenomenon of plastic deformation in the die can provide a firm and sufficiently broad basis for a full understanding of back-pull drawing.

ACKNOWLEDGMENTS

The writer wishes to thank Mr. Bolsover of Messrs. Samuel Fox and Co., Ltd., for permission to refer to their report. The report is based on experiments carried out by Mr. W. C. Heselwood of the Central Research Dept., The United Steel Companies, on an experimental bench built and loaned by Messrs. British Insulated Cables, Ltd.

APPENDIX

A very useful graphical construction for the variables of back-pull drawing has been put forward by Prof. H. W. Swift.*

The effect of back tension on the forces involved in drawing can be shown simply by a diagram such as

* The diagram and description are reproduced by his kind permission.

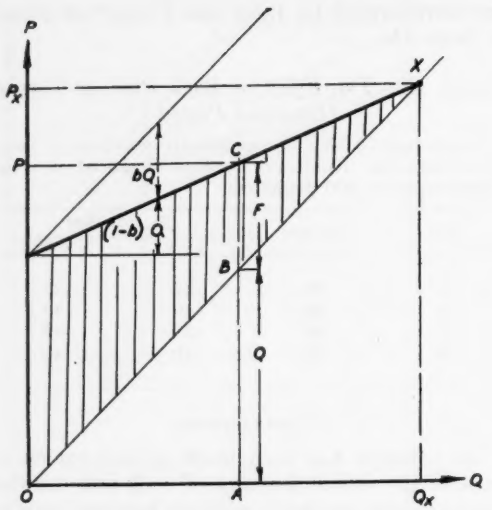

FIG. 12—Professor Swift's diagram of back-pull characteristics

Fig. 12, in which the drawing force P for a given reduction is plotted against the back-tension Q, to give a line such as P_0X. If the value of b is constant the characteristic P_0X will be a straight line, otherwise it will be curved.

In this diagram P_0 represents the basic drawing tension without back tension, whilst the point X corresponds to the limiting case where the back tension Q_x is such that there is no die reaction, so that $P_x = Q_x$ and $F = 0$. In this case the drawing operation is a simple tensile pull. In general the interval shown shaded represents the die reaction $F = P - Q$, and the (axial) tensile force in the wire as it passes through the die increases from $Q = AB$ to $P = AC$, always within the range BC.

A single characteristic line P_0X can of course only cover a single reduction ; the basic drawing tension P_0 and the back-pull factor b will both depend on and vary with the reduction.

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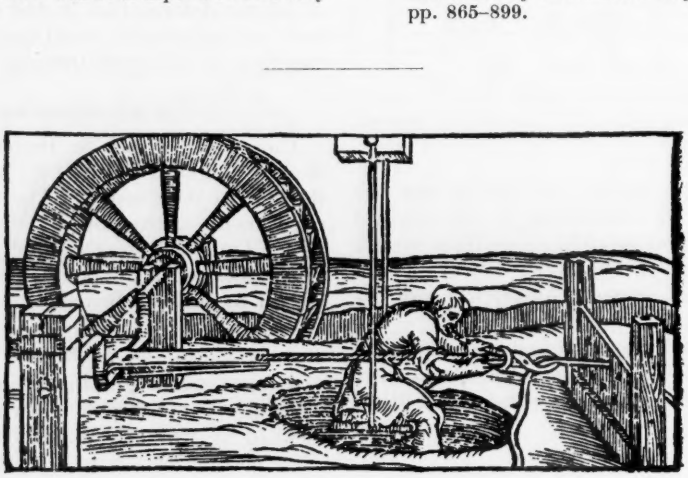

Drawing heavy wire by means of water power
(reproduced from the *Pirotechnia* of Vannoccio Biringuccio)

Service Tests of Experimental Anti-Fouling Compositions*

By H. Barnes, B.A., B.Sc., Ph.D., F.R.I.C.,† M. W. H. Bishop, B.A.,† and K. A. Pyefinch, M.A.†

SYNOPSIS

An account is given of a number of service tests in which experimental anti-fouling compositions were subjected to varying conditions of service. The results are analysed, taking into account the poison content of the compositions, the season over which the test was made, the route of the vessel, and periods in port. When all these factors are considered it may be possible to assess, with some degree of accuracy, the true performance of a composition; however, under certain circumstances, this cannot be deduced. Examples are given of the way in which the results may lead to erroneous conclusions regarding the true value of the compositions used. On the other hand, even in the absence of severe fouling, a critical examination of the settlements on the test areas, when compared with those on non-toxic patches together with a knowledge of the factors detailed above, can give reliable information of performance. This selection of small-scale service tests indicates their scope and value and suggests that further work of this type would be profitable.

INTRODUCTION

THE examination of fouling on ships and the collection of data from dry-docking report forms has given valuable information concerning the incidence and intensity of fouling at various ports throughout the world. One of the most striking features revealed by the analysis of the results is the almost complete lack of correlation between fouling state and anti-fouling composition used. One reason for this is the long interval that frequently occurs between dry-docking. Many anti-fouling compositions are of limited efficiency and they are rapidly exhausted of poison content, soon behaving as non-toxic surfaces. In view of these facts much more valuable information on the *anti*-fouling problem will accrue from detailed investigations in which more is known of the anti-fouling compositions used as well as the factors which may affect performance. During the past few years, with this end in view, an endeavour has been made by means of small-scale service tests to obtain such data.

General Plan of the Tests

Position of Patches

In general a small number of test paints have been applied to both sides of the vessel concerned. The areas were situated amidships, scuppers and other openings being avoided as far as possible and when unavoidable, notes were taken of their position in relation to the patches. Within these limits the series of plates in the best condition was chosen. The areas painted on each side were of the order of 100 sq. ft., or less; such small patches were deliberately used since previous experience had indicated that a satisfactory estimate of the performance of a composition could be obtained. More careful attention can then be given both to the preparation of the surface and to the painting; application can be made by the investigator within a reasonable period of uniform weather conditions. It is very difficult to ensure adequate supervision if application is left entirely to dockyard labour, as would be essential if, for example, the hull were quartered. The ultimate test of a composition is its performance after application under the full rigour of dockyard conditions, but in the first instance it was thought necessary to supervise application in order to separate paint performance, *per se*,

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from the vagaries consequent upon current dockyard practice.

General Conditions of Test

When tests were carried out on old vessels, the experimental anti-fouling compositions were applied over the undercoat used on the rest of the hull. If the hull received only a 'touch up' of anti-corrosive paint, it was arranged that one of the 'touched up' areas should be that used for the test. On new vessels, the experimental anti-fouling compositions were applied over two or more coats of an experimental anti-corrosive composition.

On old vessels, to ensure that no poison from previous anti-fouling coats was included in the sample of the paint taken for analysis (*see* below) it was usual either to paint the whole area or a known smaller patch within the test area, with a distinctive undercoat, *AC* 244*H*, which was pigmented a bright yellow.

In addition to the areas painted with experimental anti-fouling compositions, in order to obtain information of the fouling conditions encountered during the voyage a non-toxic control patch, which did not receive an anti-fouling coat, was left forward of the painted patches.

The weight/unit area (normally termed spreading rate) was determined for each paint applied, sometimes by weighing in the dockyard but more often by using tared cans which were reweighed on return to the laboratory.

Dockyard practice and convenience dictated the date and time at which each test was commenced. Painting had therefore to be carried out under the weather conditions prevailing at the time (full notes were taken). As will be seen from the detailed records given below, the weather conditions, fortunately, were usually favourable.

Examination at Conclusion of Test

The test areas were inspected as soon as possible after dry-docking; it was not always possible to be present when the ship dry-docked but previous arrangements with the authorities concerned ensured that the test areas were left untouched. A general inspection of the non-toxic patches, of all the test areas, and of the rest of the hull was first made. Each was then examined in detail, the kind and abundance of individual fouling organisms assessed and samples removed for subsequent laboratory examination. Even though macroscopic fouling was not evident, scrapes were taken[1] for microscopic examination. The assessment of the patch was ultimately based on all these examinations. Estimates of blistering, flaking and rusting were also made.

In order to determine poison loss, 1-in. sq. samples of paint were taken from the test areas (on old vessels, overlying the yellow undercoat). These were removed, as far as possible in large flakes, with a sharp knife, and collected in dry specimen tubes. Under dockyard conditions this method—with a little practice—particularly when the film is still soft and wet, is much to be preferred to scraping the paint film away as a powder. The samples were analysed for their copper and mercury contents, following the methods described elsewhere.[2] From the values so obtained, and the original weight per unit area, the poison loss during service could be computed.

Detailed Descriptions of Tests

A total of thirty tests of this type were begun, of which eighteen were inspected at the end of their service period, six are still on service and the remainder, for various reasons, were not inspected on dry-docking.

The number of these tests is small but it is the object of this paper not to present a general analysis of paint performance, but to point out the value of carefully controlled small-scale tests and to indicate how erroneous conclusions might easily be drawn if tests are assessed on the basis of even a full report founded only on an examination of the ship when dry docked, and it is

TABLE I (*a*)—*Details of Painting of S.S.* Bellerophon

Anti-Corrosive Coat	*AC* 244*H*	Applied 5th July, 1944, begun 10.30 hours Air temperature, 15° C.; relative humidity, 74%
Anti-Fouling Coats	*AF* 53*H*, *AF* 193*H*, *AF* 1043, *AF* proprietary *A*, *AF* proprietary *B*	Applied 5th July, 1944, from 14.30 to 17.00 hours. Air temperature and relative humidity not recorded, but warm and dry throughout

TABLE I (*b*)—*Details of Paint Applied to S.S.* Bellerophon

Composition	Mean Wt. per Unit Area, g./sq. m.	Poison Content, g./sq. m.	
		Copper	Mercury
AF 53*H*	263	46	0
AF 193*H*	417	73	15
AF 1043	314	46	23
AF proprietary *A*	342	67	0
AF proprietary *B*	717	141	110

to these ends that the examples quoted below have been selected.

Service Tests of Various Compositions under Severe Fouling Conditions

Plan of Test on S.S. Bellerophon

This test was planned to assess the performance of a series of compositions under fairly severe fouling conditions and to compare it with that under the less severe conditions obtaining in coastal waters (*see* S.S. *Marchioness of Graham*, p. 435).

Five compositions were used, three of which were experimental compositions : *AF* 53*H*, a non-mercurial composition containing 17·2% of cuprous oxide ; *AF* 193*H*, containing 17% of cuprous oxide and 4% of mercuric oxide (the latter replacing an equal amount of the red iron oxide filler in *AF* 53*H*) ; and *AF* 1043, containing 16% of cuprous oxide and 8% of mercuric oxide. The proprietary composition *A* (also used on the rest of the hull) contained 19·6% of copper, and proprietary composition *B*, 19·6% of copper and 15·3% of mercury ; the form in which these poisons were present is unknown. Details of painting are given in Tables I (*a* and *b*).

The route and times spent in port were as follows :

Liverpool/Birkenhead (before sailing)	17 days
Port Said	3 days
Suez	1 day
Port Sudan	2 days
Aden	1 day
Mombassa	10 days
Tanga Bay	2 days
Dar-es-Salaam	5 days
Beira	8 days
Durban	7 days
Capetown	5 days
St. Helena	2 days
Ascension	1 day
Freetown	8 days
Liverpool/Birkenhead (before docking)	13 days

Thus approximately 85 days had been spent in harbour and 83 days at sea. The vessel entered dry dock on 18th December, 1944.

The Results of Examination of Fouling on S.S. Bellerophon *after Dry-Docking*

(i) *Fouling and Paint Condition*

The test areas were inspected on 19th December, 1944, the day after the ship had entered dry dock. At the time of this inspection the bottom plating had been cleaned, so it was not possible to inspect the general state of fouling on the hull, but routine samples had previously been taken in the usual way by the foreman painter employed by Messrs. Alfred Holt and Co., and these formed a valuable supplement to the samples collected from the test areas and have enabled a tentative fouling history to be constructed, which is given later in this section.

Details of the fouling present are shown in Table IV, which gives :

(*a*) *The General Rating*—given on inspection in dry dock, in terms of slime, grass, hydroid, and shell. Ratings for each category are given on a 0–7 scale, details of which have been given in an earlier publication.

(*b*) *The Detailed Fouling*—based on subsequent examination of samples.

(*c*) *The Fouling Category*—given in accordance with the scheme previously described[1] and based on the data provided by (*a*) and (*b*). Following this scheme a paint can be placed, according to the nature of the fouling present, in one of five categories, designated by the symbols *O*, O_1, *f*, *F*, and *FF*. If the fouling present on the paint indicates inclusion in any of the last three categories, the paint is no longer offering adequate protection against fouling settlement, but if inclusion in either of the first two categories is indicated, the paint is rated as unfouled. Sometimes, though inclusion in one category is strictly correct, there are signs that further fouling settlement could soon occur ; such a state is indicated by the use of two symbols, *e.g.*, O_1/f, f/F, etc. These symbols are also used in Tables IV, VI, XII, XIII, and XIV.

Paint condition was satisfactory, with the exception of *AF* proprietary *B*, which had cracked

Table II—*Paint Condition of S.S.* Bellerophon

Side	Patch	Undercoat	Mean Rusting Estimate of Area Painted, %
Port	*AF* 53*H*	*AC* 244*H*	Tr
	AF 193*H*		Tr
	AF 1043		Tr
	AF proprietary *A*		...
	AF proprietary *B*		Tr
Starboard	*AF* 53*H*	*AC* 244*H*	Tr
	AF 193*H*		1
	AF 1043		Tr
	AF proprietary *A*		Tr
	AF proprietary *B*		Tr

Tr indicates trace

Table III—*Rate of Loss of Poison* (*S.S.* Bellerophon)

Composition	Average Rate of Loss, mg./1000 sq. cm./day		Original Poison Lost, %	
	Copper	Mercury	Copper	Mercury
AF 53*H*	7·7	0	42	0
AF 193*H*	3·4	3·3	9·5	38
AF 1043	4·4	3·4	18	27
AF proprietary *A*	32·0	0	89	0
AF proprietary *B*	37·0	33·2	46	68

TABLE IV—*Fouling on Test Areas of S.S.* Bellerophon

Composition	Side[a]	General Rating	Detailed Fouling[b]	Fouling Category
AF 53*H*	Starboard	Slime ... ... 1 Hydroid ... ... Tr Shell (w)[c] ... Tr	*Schizonema* *Amphora* Other naviculoid diatoms *Enteromorpha* Hydroid stolon *Hydroides* *Ectocarpus*	O_1 (O_1/f (?))
	Port	Slime ... ... 2 Shell (b)[c]... ... Tr	...	O_1 (O_1/f (?))
AF 193*H*	Starboard	Slime 3	Bacterial slime *Enteromorpha* (?) *Schizonema* (?)	*O*
	Port	Slime 2	...	*O*
AF 1043	Starboard	Slime 4	*Amphora* *Schizonema* *Enteromorpha*	*O*
	Port	Slime 2	...	*O*
AF proprietary *A*	Starboard	Slime ... ... 3 Shell (w)[c] ... Tr	Naviculoid diatoms *Enteromorpha* *Hydroides*	O_1
AF proprietary *B*	Starboard	Slime ... ... 1 (?)	Very slight bacterial slime	O_1
	Port	No visible fouling	...	*O*
AC 173[d]	Starboard	Grass ... ... 3 Hydroid ... ... Tr Shell (w.b.)[c] ... 3 Misc.[e] 1	*Enteromorpha* *Hydroides* *Spirorbis* *Balanus* *Membranipora* *Ectocarpus* *Ulva* Hydroid stolon	*FF*
	Port	Grass ... ... 3 Shell (w.b.)[c] ... 4 Misc. 2	...	*FF*
		Grass ... ... 3 Shell (w.b.)[c] ... 4 Misc. 2	...	*FF*

Tr indicates trace

a ... Details of fouling are given for the patches painted on the starboard side only, since the time was not available for the removal of samples of fouling from the patches on the port side.
b ... The genera found are given in approximate order of abundance of occurrence in the sample taken.
c ... Letters in parentheses show the type of shell fouling found ; (w) indicates tubeworms and (b) barnacles. Where more than one type of shell fouling was present, the order of the key letters is that of frequency of occurrence.
d ... As a non-toxic control area.
e ... This category includes those fouling forms not classified as slime, grass, hydroid or shell ; in the present instance it denotes the encrusting Polyzoan, *Membranipora*.

and flaked badly. In Table II, only the mean percentage of the area which rusted is shown, because it is felt that this most clearly indicates the general performance of the protective coatings and it is also the factor most likely to influence fouling settlement or loss.

(ii) *Loss of Poison in Service*

The rate of loss of poison from the paints and the percentage of the original poison lost are shown in Table III.

Discussion

(i) *The Non-Mercurial Compositions*

The rate of loss of copper from *AF* 53*H* would suggest that this paint should have been fouled if the average rate of loss had been maintained throughout the voyage. The paint was almost clean when the ship docked. It may be that the higher temperature in the tropical waters was sufficient to raise the rate of loss to a value adequate to prevent fouling. Alternatively, the mean value of 7·7 may be the result of a high loss during the first part of the voyage and a much smaller one in the second part, for if such a state of affairs were combined with a lack of settling organisms during the second part of the voyage it would explain the clean state of the paint when docked. The biological observations suggest incipient failure and the results of the analyses would indicate that had the ship encountered heavy fouling during the latter part of the voyage, settlement would have taken place.

Composition *AF* proprietary *A* is virtually exhausted of poison and would have had little anti-fouling action for some time, which again suggests that little fouling had been encountered during the later stages of the voyage, although it is to be noted that whilst the test areas of this paint were clean, on other parts of the hull to which this paint had been applied, fouling had settled. The figures in Table III suggest that the paint has far too high a rate of loss to use the contained copper to best advantage, and had the weight per unit area not been high it seems almost certain that with this considerable rate of loss the paint would have fouled.

(ii) *The Copper–Mercury Compositions*

The rates of loss of mercury from both *AF* 193*H* and *AF* 1043 were high and of themselves probably adequate to prevent fouling. The small loss of copper from these paints in the present test might indicate that they are virtually behaving as ' mercury ' paints. If applied at this weight per unit area, both these paints may be expected to give protection for possibly a further 3–6 months.

The sample of *AF* proprietary *B* used in this test is the most wasteful paint yet encountered ; the leaching rates both of copper and of mercury being much higher than the known critical leaching rate. The sample was from an old batch of paint which had possibly deteriorated to such an extent that, when put into service, breakdown of the film as a whole had taken place and protection had only been attained by the abnormally high weight per unit area. This suggestion is supported by the poor state of this paint film at the end of the test, severe cracking and extensive flaking of the anti-fouling coat having taken place.

Suggested Fouling History of S.S. Bellerophon

The following account is based on material taken from the non-toxic patches and from material collected from the bottom flats. As has frequently been noted, fouling seems to have been generally heavier below the bilge keel than on the sides above this level.

The probable order of settlement is indicated when one organism is found to have settled on top of another. Care must be taken to distinguish cases of overgrowth, *e.g.*, by the rapidly growing barnacle *Balanus tintinnabulum* when it tends to smother the other common species of barnacle *B. amphitrite*, which grows more slowly. Using present limited knowledge of growth rate as well as the probable effects of such factors as temperature and salinity in the ports of call, it is thus possible to suggest, very tentatively, a fouling history of this voyage.

It should be emphasized that at present such reconstructions of the sequence of settlement of fouling organisms are little more than reasoned guesswork, and that much more material, collected both from ocean-going vessels entering dry dock in this country and from smaller craft in local service in ports abroad, is needed before the level of certainty can be appreciably raised. In the particular voyage under discussion, the nature of the route and the variety of fouling which had settled have been unusually helpful ; it is by no means always possible to work out such a detailed history.

The reconstructed fouling history is given below, and as an introduction one or two general statements may be made :

(*a*) With the exception of the small white barnacles described as settling towards the end of the voyage, all fouling was apparently alive when sampled (fouling is classified as ' living ' when the body of the animal is present in a well-preserved condition).

(*b*) It is assumed that, although tropical or subtropical species of fouling organisms such as barnacles may be alive when sampled, growth will have been negligible after entry into colder

waters (in the present instance, roughly after the end of November). Observations on the growth rate of the tubeworm *Hydroides* (based on specimens settled on raft-exposed surfaces at Millport) suggest that in this genus growth of the tube may continue even when the water temperature is decreasing. This does not necessarily mean, however, that specimens indigenous to warmer waters will continue to grow when subjected to the sudden decrease in temperature involved in a voyage, such as that from the Gold Coast to this country during the winter months.

(*c*) It will be noted that whilst deductions as to the port of settlement of barnacles and calcareous tubeworms figure prominently in this history, nothing is said about other fouling organisms. Such organisms either do not lend themselves readily to this form of analysis (*e.g.*, Hydroids, for which, because of their creeping habit of growth, the order of settlement cannot be determined) or were present in quantities too small to allow adequate analysis to be made (*e.g.*, the Polyzoan *Membranipora*; the Algae, *Ectocarpus*, *Ulva*, etc.) or for which too little is known about rate of growth (*e.g.*, the green Alga *Enteromorpha*).

Birkenhead, 5th–21st July

During this period the non-toxic control areas seem to have missed any settlement, although *Balanus improvisus* was settling quite heavily in some parts of the Mersey at this time. The initial period of toxicity which has been observed, even for paints formulated without poisons, may partly have accounted for this lack of settlement.

Port Said, 12th–15th Aug.; Suez, 15th–16th Aug.; Port Sudan, 19th–21st Aug.; Aden, 24th–25th Aug.

At any of these ports the tubeworm *Hydroides* is almost certainly a prevalent fouling organism, yet there was little, if any, sign of this worm settling so early. The period in each port is, however, short and if, as is possible, *Hydroides* settles intermittently the ship may well have missed periods of settlement.

Mombassa, 3rd–13th Sept.; Tanga Bay, 13th–15th Sept.; Dar-es-Salaam, 16th–21st Sept.; Beira, 25th Sept. to 3rd Oct.

Settlement began somewhere down the East African coast. Some specimens of *Balanus amphitrite* (var. *communis* and var. *niveus*) had reached a diameter of 13–14 mm. on dry-docking, and these probably settled during this period; some settlement of *Hydroides* and oysters probably occurred at about this time, probably after the barnacle settlement just mentioned. None of these settlements was at all heavy.

Durban, 6th–13th Oct.

The probable site of settlement of the main bulk of the barnacles, especially *Balanus tintinnabulum* var. *communis* (?). This species had reached a diameter of 8–12 mm. on dry-docking. Some of this settlement may have occurred at the next port of call, though this is thought to be less likely than settlement at Durban.

Capetown, 16th–21st Oct.

Probably no settlement, though a few *Balanus amphitrite* may have settled here.

St. Helena, 28th–30th Oct.; Ascension, 2nd–3rd Nov.

There is a probable settlement of *Balanus tintinnabulum*, a very pale variety not previously seen in fouling samples; these barnacles had reached a diameter of 3–5 mm. on dry-docking.

Freetown, 7th–15th Nov.

The specimens of *Balanus tintinnabulum* just mentioned may have settled at this port, but it is suspected that this variety may not occur at Freetown. A fairly heavy settlement of *B. trigonus* occurred early in the stay at this port (these barnacles had grown to a diameter of 3–5 mm. on dry-docking) and there was also a later settlement of *B. amphitrite* var. *communis* (3 mm. in diameter on dry-docking). Towards the end of the period in this port, it is probable that a settlement also occurred of *B. amphitrite* var. *niveus* (the small, white barnacles mentioned earlier). These were approximately 1–2 mm. in diameter on dry-docking and were nearly all dead when sampled. The marked change of environment encountered during the rest of the voyage, may have been the cause of their death and it has also been shown experimentally that very small barnacles of some species cannot survive a period of rapid water movement of the order of 8 knots.[3]

Liverpool, 5th–19th Dec.

It is just possible that these small barnacles were specimens of *Balanus improvisus* which had settled immediately before the ship entered dry dock (specific identification of very small barnacles is virtually impossible), but there is no evidence, from non-toxic plates exposed in the Mersey over this period, that such a settlement took place and further, if settlement had occurred locally, it is difficult to see why so many of these barnacles were dead when the ship was inspected.

Comments

Since the copper–mercury paints were not fouled at the end of the voyage and as their leaching rates have been high throughout, there is little to add to the results already given.

Two alternatives are suggested on page 433, for the lack of fouling on *AF* 53*H*, either the effect of temperature in raising the rate of loss of poison in tropical waters, or the lack of fouling in the latter part of the voyage. Reconstruction of the fouling history indicates, however, that settlement *did* occur over the second half of the voyage, which supports the former hypothesis.

If this is the correct explanation, *AF* proprietary *A* should certainly have been fouled during the second half of the voyage. Samples of fouling from this paint taken from below the bilge keel (on which most of the fouling history is based) show that settlement almost certainly *had* taken place. The absence of fouling on the patch painted with this composition within the test area is therefore anomalous; possibly this may be explained by the general lack of fouling on the sides of the ship immediately above the bilge keel.

Plan of Test on S.S. Marchioness of Graham (*1st Test*)

A number of tests will be described which have been carried out on Clyde passenger vessels, but rather more detailed attention will be given to the S.S. *Marchioness of Graham*, the first of these, for the following reasons. The three experimental anti-fouling compositions used were from the same batches as those tested on S.S. *Bellerophon*, and the results afford a useful comparison of data on performance under temperate coastal service with tropical ocean-going service. This test also clearly shows the extent of information that *can* be obtained under the former service conditions when due attention is paid to seasonal factors.

The only differences between the series of compositions used in the present test (*see* Tables V (*a*) and V (*b*)) and those on S.S. *Bellerophon* were that the proprietary composition (*C*) in this instance contained 16·6% of copper and that, since this test was started in May, the experimental compositions were subject to less 'ageing.'

This vessel works a passenger service in the Clyde, her usual route during the summer months being between Wemyss Bay, Largs and Millport. At night she is usually berthed at Millport Old Pier and altogether approximately 50% of her period of service is spent under way. She is thus exposed to fairly heavy fouling conditions and it has been the practice of the Caledonian Steam Packet Co., Ltd., her owners, to dock this vessel at roughly six-monthly intervals.

The S.S. *Marchioness of Graham* left dock on 18th May, and was at sea for 147 days before again being docked, when samples were taken and the ship inspected.

TABLE V (*a*)—*Details of Painting, S.S.* Marchioness of Graham

Anti-Corrosive Coat	*AC* 244*H*	Applied 15th May, 1944, application begun 14.30 hours. Dry, with sun and light breeze
Anti-Fouling Coats	*AF* 53*H*, *AF* 193*H*, *AF* 1043, *AF* proprietary *C*	Applied 16th May, 1944, 10.00 to 16.00 hours Air temperature, 15·0° C. (port side), 12·2° C. (starboard side), mean relative humidity 60%

TABLE V (*b*)—*Details of Paint Applied to S.S.* Bellerophon

Composition	Mean Wt. per Unit Area, g./sq. m.	Poison Content, g./sq. m.	
		Copper	Mercury
AF 53*H*	193	33·6	0
AF 193*H*	254	42·4	9·5
AF 1043	427	61·1	30·6
AF proprietary *C*	141	21·4	0

The Results of Examination of Fouling on S.S. Marchioness of Graham *after Dry-Docking*

(i) *Fouling and Paint Condition*

At the time of inspection the underwater surfaces, other than the test areas, had been cleaned, so that it was not possible to compare their condition with that of the hull as a whole, though the inclusion of patches painted with the proprietary composition used on the hull in the experimental series, enabled its performance to be compared with that of the experimental formulations. The foreman in charge stated that fouling was not heavy.

Details of the fouling found are given in Table VI in which the same basis of classification is used as for the test on S.S. *Bellerophon* (*see* p. 432).

Details of paint condition are given in Table VII.

(ii) *Loss of Poison in Service*

The rate of loss of poison from the paint and the percentages of original poison lost are shown in Table VIII.

Discussion

(i) *The Non-Mercurial Compositions*

It is clear that these compositions are virtually exhausted of poison and no anti-fouling properties should therefore remain. This is in entire agreement with the assessments given in Table VI.

TABLE VI—*Fouling on Test Areas on S.S.* Marchioness of Graham

Composition	Port			Starboard		
	General Rating	Detailed Fouling[a]	Fouling Category	General Rating	Detailed Fouling[a]	Fouling Category
AF 53*H*	Grass ... 3	*Ectocarpus* *Ulothrix* *Achnanthes* *Enteromorpha*	*F*	Grass ... 4	*Ectocarpus* *Ulothrix* *Achnanthes*	*F*
AF 193*H*	Grass ... 1	*Ectocarpus* *Achnanthes*	*f* (?)	Grass ... 1 Shell ... Tr	*Achnanthes* *Ectocarpus* *Ulothrix* *Membranipora*	O_1/f
AF 1043	Grass ... Tr	*Achnanthes* *Ectocarpus*	O_1/f	Grass ... 2	*Achnanthes* *Enteromorpha* *Ectocarpus*	O_1/f
AF proprietary *C* ...	Grass ... 3 Shell ... Tr	*Ectocarpus* *Achnanthes* *Ulothrix* *Balanus*	*F*	Grass ... 2	*Ectocarpus* *Achnanthes*	*F*

Tr indicates trace

a ... The genera found are given in approximate order of abundance of occurrence in the sample taken

In view of the fact that when the ship is in motion copper is being lost from the anti-fouling paint at a rate greater than that when in port, and that the leaching rate of compositions containing cuprous oxide as the sole poison tends to drop in the later stages of soaking, it might be predicted with safety that not only were the paints incapable of preventing settlement but that they had been in this state for some time.

(ii) *The Copper–Mercury Compositions*

In view of the comparatively high copper losses it is clear that there is a great waste of mercury in both these compositions. The analytical results indicate that neither of these compositions should be fouled, again in general agreement with the fouling assessments. Both compositions still have adequate reserves of poison ; *AF* 193*H* might be expected to last a further 3–4 months and *AF* 1043 a further 6 months, provided that the rate of release of poison over the service period was maintained. The fouling assessments, however, suggest that both these compositions were on the border line between adequate protection and the reverse, so that this prediction, based solely on chemical evidence, might not have been fulfilled in practice.

TABLE VII—*Paint Condition on S.S.* Marchioness of Graham (*1st Test*)

Side	Patch	Undercoat	Mean Rusting Estimate of Area Painted, %
Port	*AF* 53*H*		Tr
	AF 193*H*		Tr
	AF 1043	*AC* 244*H*	0
	AF proprietary *C*		0
Starboard	*AF* 53*H*		0
	AF 193*H*		Tr
	AF 1043	*AC* 244*H*	Tr
	AF proprietary *C*		Tr

Tr indicates trace

Comments

Though fouling was not heavy on any of the experimental compositions applied in this test it may be concluded that *AF* 53*H* (containing cuprous oxide only) and proprietary composition *C* had ceased to offer adequate protection, and that the two copper–mercury formulations, though

TABLE VIII—*Rate of Loss of Poison on S.S.* Marchioness of Graham

Composition	Average Rate of Loss, mg./1000 sq. cm./day		Original Poison Lost, %	
	Copper	Mercury	Copper	Mercury
AF 53*H*	14·8	0	71	0
AF 193*H*	11·7	3·4	54	58
AF 1043	9·4	4·1	30	25
AF proprietary *C*	15·1	0	86	0

TABLE IX—*Service Tests Carried Out Using* AF *23H and* AF *28H*

Name of Vessel	Type	Registered Tonnage	Date of Start of Test[a]	Date of Completion of Test[b]	Period, days	Mean Wt. of Wet Coat Applied, g./sq. m.
S.S. *Marchioness of Graham*[c] (2)	Clyde passenger vessel	585	16/10/44	26/2/45	133	156 (23*H*) 220 (28*H*)
S.S. *Marchioness of Graham*[c] (3)	Clyde passenger vessel	585	2/3/45	10/5/45	69	83 (23*H*) 95 (28*H*)
M.V. *British Might*[d]	Tanker	8200	29/3/45	3/12/45	249	223 (23*H*) 161 (28*H*)
S.S. *Pandorian*[e]	Cargo liner	4159	28/3/45	6/2/46	315	61 (23*H*) 55 (28*H*)
S.S. *Marchioness of Graham*[e] (4)	Clyde passenger vessel	585	14/5/45	11/2/46	273	? (23*H*) ? (28*H*)
S.S. *Empire Bromley*[f]	Coaster	1060	26/5/45	12/2/46	262	107 (23*H*) 107 (28*H*)
S.S. *Empire Lewisham*[g]	Coaster	1060	8/11/45	3/7/46	237	122 (23*H*) 140 (28*H*)

a ... The date quoted is that on which the paints were immersed.
b ... The date of dry-docking.
c ... Test carried out by permission of the Chief Marine Superintendent, L.M.S. Railway Co., Ltd.
d ... Test carried out by permission of the British Tanker Co., Ltd., and Messrs. Harland and Wolff, Ltd.
e ... Test carried out by permission of Ellerman Lines, Ltd. (City Line).
f ... Test carried out by permission of Messrs. John Kelly, Ltd., and Messrs. George Brown (Marine), Ltd.
g ... Test carried out by permission of Messrs. J. Hay and Sons, Ltd., and Messrs. George Brown (Marine), Ltd.

generally clean in appearance, were approaching the border line between adequate and inadequate protection against fouling.

SERVICE TESTS USING *AF 23H* AND *AF 28H*

The foregoing tests, showing almost complete agreement between the results of chemical and biological observations, show how the true performance (in some detail), of an anti-fouling composition is obtained when all the major factors are known and can be taken into consideration. Further, a dockyard inspection alone could in these cases have given a correct interpretation of the overall performance during the voyage.

It is now proposed to describe a series of tests in which, for a variety of reasons, a true impression of the merits of the compositions tested would not have been given by dockyard inspection alone.

The two anti-fouling compositions selected for these tests, *AF 23H* (16·4% of Cu_2O, 3·7% of HgO) and *AF 28H* (23·8% of Cu_2O, 5·9% of HgO) were two members of a series which were tested by means of leaching-rate determinations and raft exposures during 1944. The performance of the original small experimental batches (100 g. approximately) was distinctly promising. It was therefore decided to test these paints under service conditions and arrangements were made for the preparation of bulk batches for this purpose.

Twelve small-scale tests were carried out using these compositions, five on newly constructed vessels, when the compositions were applied immediately before launching, and seven on old vessels, the paints then being applied in dry dock. Seven of these tests were inspected after service, by members of the Millport team, but it is to be regretted that full details of the performance of the experimental compositions are not available for the remainder—two of which were made on new vessels and three on old vessels.

Before the general implications of this series of tests can be discussed it is necessary briefly to describe them separately, since the interpretation

TABLE X—*Summary of Results of Tests Using* AF *23*H *and* AF *28*H

In the Table the test areas are recorded as "Fouled" or "Unfouled" following dockyard practice and not according to the results of detailed biological examination.

This scheme has been adopted so that the subsequent discussion of the detailed biological observations will emphasize the disparity between true performance and that assigned by dockyard practice, following which all the compositions used in the two tests previously discussed would have been rated as "Unfouled."

Name of Vessel	General Estimate of Paint Condition[a]	Condition		Remarks
		Anti-Fouling Coatings	Non-Toxic Patches	
S.S. *Marchioness of Graham* (2) ...	Fair to good	*23H* Unfouled *28H* Unfouled	[b]	Winter run, temperate waters
S.S. *Marchioness of Graham* (3) ...	Satisfactory	*23H* Unfouled *28H* Unfouled	Unfouled	Short period, temperate waters, fouling conditions moderately intense
M.V. *British Might*	Poor	*23H* Unfouled *28H* Unfouled	(?)[c]	North Atlantic run, visits to Manchester Ship Canal
S.S. *Pandorian*	Satisfactory	*23H* Fouled *28H* Unfouled	Fouled	Some time in Mediterranean, long service period
S.S. *Marchioness of Graham* (4) ...	Satisfactory	*23H* Unfouled *28H* Unfouled	Fouled	Summer and winter run, temperate waters
S.S. *Empire Bromley*	Fair	*23H* Unfouled *28H* Unfouled	Unfouled	Coastal runs in temperate waters; fresh-water berthings
S.S. *Empire Lewisham*	Fair	*23H* Unfouled *28H* Unfouled	Fouled	Coastal runs in temperate waters; fresh-water berthings

a ... These estimates refer to those parts of the test areas which had, in tests on newly constructed vessels (*British Might*, *Empire Lewisham*, and *Empire Bromley*), received all three paint coatings. They do not refer to the non-toxic control areas, which had only received two anti-corrosive coats.

b ... Non-toxic patches were not present within the test areas in this test.

c ... Paint condition was so unsatisfactory that the non-toxic patches were inadequate as guides to the fouling settlements encountered.

TABLE XI—*Summary of Paint Condition for Service Tests (given in Table IX) Carried Out Using* AF23H *and* AF *28*H

Name of Vessel	Side	Patch	Undercoat	Mean Rusting Estimate of Area Painted, %
S.S. *Marchioness of Graham* (2) ...	...	...	Proprietary	Full details not available, but certainly less than 5%
S.S. *Marchioness of Graham* (3) ...	Port	Non-toxic		Tr
		23*H*		Tr
		28*H*	Proprietary	Tr
	Starboard	Non-toxic		Tr
		23*H*		Tr
		28*H*		Tr
M.V. *British Might*	Port	Non-toxic		70
		23*H*		60
		28*H*	*AC* 174	45
	Starboard	Non-toxic		95
		23*H*		45
		28*H*		45
S.S. *Pandorian*	Port	Non-toxic		2
		23*H*		2
		28*H*	Proprietary	5
	Starboard	Non-toxic		1
		23*H*		0
		28*H*		Tr
S.S. *Marchioness of Graham* (4) ...	Port	Non-toxic		0(?)
		23*H*		Tr
		28*H*	Proprietary	Tr
	Starboard	Non-toxic		0
		23*H*		Tr
		28*H*		Tr
S.S. *Empire Bromley*	Port	Non-toxic		5
		23*H*		5
		28*H*	*AC* 173	15
		Hull	Proprietary	80
	Starboard	Non-toxic	*AC* 173	15
		23*H*		10
		28*H*		15
		Hull	Proprietary	90
S.S. *Empire Lewisham*	Port	Non-toxic	*AC* 174	25
		23*H*		15
		28*H*		10
		Hull	Proprietary	25
	Starboard	Non-toxic		100
		23*H*	AC 174	10
		28*H*		15
		Hull	Proprietory	30

Tr indicates trace

of any one depends upon a knowledge of its conditions. Tables IX, X, and XI summarize the details of those tests in this series which were completed.

S.S. Marchioness of Graham (*2nd Test*)

The service period extended over 4½ months, approximately, and the conditions of service were closely comparable with those described for the earlier test on this vessel (*see* p. 435). When inspected, the test areas were found to be unfouled, a condition which also obtained over the hull as a whole. Microscopic examination of samples from the paint surface showed the presence of a thin slime film which may have been bacterial in origin and which contained a good deal of debris.

S.S. Marchioness of Graham (*3rd Test*)

This test lasted only 69 days, as the S.S. *Marchioness of Graham* again entered dry dock early in May. When inspected, the test areas appeared to be clean, but closer examination revealed the presence of a settlement of small barnacles. On the non-toxic control areas these extended upwards from the bilge keel (the lower limit of the test areas) for a distance of roughly 3½ ft. (the total depth of the test area was approximately 5 ft.) ; on the patch painted with *AF* 23*H*, the small barnacles had settled up to a distance of approximately 2 ft. from the bilge keel whilst on the patch painted with *AF* 28*H* the upward extent of settlement was limited to 1½ ft. and ended abruptly at a plate lap situated at this distance above the bilge keel.

Loss of poison from the experimental anti-fouling coatings was as follows :

Composition	Mean Rate of Copper Loss, mg./1000 sq. cm./day	Original Copper Lost, %
AF 23*H*	10·5	58
AF 28*H*	13·3	43

M.V. British Might

This test was the first of this series of tests to be carried out on a newly-constructed vessel and the first, therefore, in which the painting systems for the test areas consisted wholly of experimental compositions.

The test area on each side comprised a strip covering three frame spaces fore and aft (roughly 9 ft.) and extending upwards from the bilge keel to the lower edge of the topside painting. The whole of the test areas received two coats of *AC* 174 (applied on successive days), followed by coats of *AF* 23*H* and *AF* 28*H* applied respectively to two of the three frame spaces within each area, the third being left as a non-toxic control patch. The anti-fouling coatings were applied the day following that of the application of the second anti-corrosive coat and launching followed some 27 hr. later.

The M.V. *British Might* proceeded straight on to service after fitting out, so that the test covered both the fitting out period (69 days) and the first period of service (180 days). Painting took place towards the end of March and the vessel next entered dry dock at the beginning of December. The M.V. *British Might* chiefly operated in the North Atlantic, though on two occasions she visited Corpus Christi (Gulf of Mexico). On three visits out of four to this country she ended her run in the Manchester Ship Canal. Throughout the period her stays in port had been short, the average stay being of four days and the longest one of ten days.

As is clear from Table XI, the general paint condition over the test areas was very unsatisfactory, so that the areas available for the assessment of fouling were very limited.

No macroscopic fouling was present on those areas which retained an intact anti-fouling coating, and microscopic examination of the greenish-grey deposit present on them revealed only the presence of the diatom *Amphora*. The test areas must therefore be rated as unfouled. The extensive deterioration of the paint film over the non-toxic control areas eliminated any evidence they might have presented of the sequence of fouling settlements encountered.

Loss of poison from the experimental compositions tested was as follows :

Composition	Mean Rate of Copper Loss, mg./1000 sq. cm./day	Original Copper Lost, %
AF 23*H*	8·5	59
AF 28*H*	5·1	37

S.S. Pandorian

In this test the experimental anti-fouling compositions were again applied over the proprietary protective composition used over the whole of the bottom plating. Though the protective composition was applied earlier in the day on which application of the anti-fouling test compositions was made, it was dry when the anti-fouling coats were applied. The dock was flooded just over 18 hr. after the anti-fouling coats were painted.

The test was started towards the end of March and dry-docking next took place early in the February of the next year. This service period of 10½ months can be divided into two parts ; the first period extended from the time of painting until early October, the second from late November until the following February, the interval between the two periods having been spent in the Manchester Ship Canal. During the earlier period the S.S. *Pandorian* made four trips to Portugal and

Gibraltar, and during the later period she visited a number of central and eastern Mediterranean ports.

When inspected in dry dock after service, fouling was present on the non-toxic control areas and on both experimental anti-fouling compositions. The amount of fouling present on the non-toxic patches was greater than that on the toxic test patches, but the kinds of fouling organism present (barnacles—all dead, empty shells, a *Tubularian* hydroid, the tubeworm *Hydroides*, a small number of oysters, and isolated patches of the encrusting ' coral ' *Membranipora*) on both were virtually identical. This indicates that at the time when fouling settlement occurred the toxic patches were not offering adequate protection.

S.S. Marchioness of Graham (*4th Test*)

This test was a continuation of that described on p. 440, for not only were the same test areas and the same experimental anti-fouling compositions used but the starboard side patches were re-immersed without further application of paint and untouched except for a light cleaning (which removed the barnacle settlement previously noted) and for a re-touching of the coating where paint samples had been removed.

This was done while the S.S. *Marchioness of Graham* was in dry dock in mid-May ; she next dry-docked in the middle of the following February. The port-side test areas had thus been exposed for a period of 273 days (as shown in Table IX) but the starboard-side test areas had been exposed for two periods, one of 69 days and the other of 273 days, separated by an interval of 4 days during which they were out of the water when the ship was in dry dock.

When finally inspected in dry dock, the non-toxic control areas were found to be heavily fouled. The green weeds *Enteromorpha* and *Ulva* were present in some quantity near the water line, the brown weed *Ectocarpus* was common over the whole areas, and the red weed *Ceramium* was also present. Animal fouling organisms (in order of abundance) included barnacles (*Balanus crenatus*), tubeworms (*Pomatoceros*), and encrusting ' coral ' (*Membranipora*). Macroscopic fouling was absent, however, from both test areas on both the port and starboard sides. A greenish-grey deposit was present which proved, on microscopic examination, to contain diatoms (*Achnanthes*) and the young stages of the weeds *Enteromorpha* and *Ectocarpus*.

S.S. Empire Bromley

The test on this newly constructed vessel was begun in May, 1945, when the test areas received two coats of *AC* 173 and, over appropriate parts, one coat of *AF* 23*H* and *AF* 28*H*, all of which were applied before launching. The S.S. *Empire Bromley* did not enter dry dock after fitting out so that the total period of the test included the fitting out period. Only 32 days were spent over the latter process, the remainder of the 262 days of the test having been spent in service.

The S.S. *Empire Bromley* was at first engaged in a cross-channel service but from the end of November until her dry-docking the following February, she had been working between England and Ireland with some coastal runs along the west coast. Roughly half her service period had been spent in port but her calls rarely exceeded two or three days and were on at least eleven occasions in water of low salinity.

When finally inspected in dry dock, except for *Enteromorpha* and *Ulva* at the water line on one of the patches painted with *AF* 23*H* the test areas were found to be virtually clean. The non-toxic control patches also showed a well-marked belt of these algae at the water line, but below this level fouling was light, with only a few barnacles (possibly *Balanus improvisus*) and traces of *Membranipora* present.

Paint condition was not satisfactory over the test areas but, as shown in Table XI, it represented a very marked improvement over that of the paint elsewhere on the hull.

S.S. Empire Lewisham

This test closely parallels that just described on the S.S. *Empire Bromley*. The two vessels were identical in design, the test areas were situated in the same region and were similar in extent. Painting was again completed before launching and service conditions were closely similar, *i.e.*, mainly coastal routes in temperate waters, short stays in port and frequent berthing in water of low salinity. In the present instance, however, the experimental anti-fouling coatings were applied over two coats of *AC* 174.

The S.S. *Empire Lewisham* was launched early in November, 1945, and next entered dry dock early in the following July. Of this 237-day period 152 days had been spent in service, of which 94 days had been spent in port and 58 days at sea.

Inspection of the test areas in dry dock showed that the only fouling present was small barnacles (none exceeded 2 mm. in diameter and all were dead) ; these were rated as frequent on the non-toxic control areas, as occasional on the patches coated with *AF* 23*H*, and as very rare on the rest of the hull. Specific identification of such small specimens is not possible and their date of settlement is also uncertain. They probably settled in the spring and were killed by an estuarine

TABLE XII—*Raft Anti-Fouling Performance of Complete Experimental Painting Schemes*

Paint Schemes	Mean Wet Wt. of *AF* Applied, g./sq. m.	Fouling State after Exposure								Estimated *AF* Life, days
		13 days	20 days	25 days	65 days	96 days	124 days	157 days	185 days	
AC 173/*AC* 173/*AF* 23*H*	107	*O*	*O*	*O*	*O*	*O*	*O*	*F*	*F*	140
AC 174/*AC* 174/*AF* 23*H*	150	*O*	*O*	*O*	*O*	*O*	*O*	*F*	*F*	140
AC 173/*AC* 173/*AF* 28*H*	136	*O*	O_1	O_1	O_1/f	O_1/f	O_1/f	*F*	*F*	125 (?)
AC 174/*AC* 174/*AF* 28*H*	123	*O*	O_1	O_1	O_1/f	O_1/f	O_1/f	*F*	*F*	125 (?)
Dates of assessments (immersed 19th Oct., 1944 ; withdrawn 19th June, 1945)	Day	1	8	13	23	23	20	25	22	
	Month	xi	xi	xi	xii	i	ii	iii	iv	

docking shortly afterwards. The evidence from the non-toxic control areas suggests that this was the only fouling settlement encountered during the service period.

RAFT EXPOSURES OF *AF* 23*H* AND *AF* 28*H*

As has been mentioned in the opening paragraph of the preceding section, the original raft exposures of the experimental compositions, when applied at their normal weight per unit area (*AF* 23*H*, 194 g./sq. m. ; *AF* 28*H*, 200 g./sq. m.) had anti-fouling properties promising enough to warrant their use in service tests. Immersed in December, 1943, both compositions were unfouled at the end of the following summer, and they did not actually become fouled until April, 1945.

Raft control tests of the bulk batches used in the service tests just described were not made for each of the service tests carried out, but a series of such exposures were made immediately after the bulk batches had been received in the autumn of 1944.

The following raft control exposures were made :

(*a*) Exposures of the paint systems :

AC 173/*AC* 173/*AF* 23*H*
AC 173/*AC* 173/*AF* 28*H*
AC 174/*AC* 174/*AF* 23*H*
AC 174/*AC* 174/*AF* 28*H*

covered service tests of these compositions on new ships where all the painting was completed before launching.

(*b*) Exposures of the paint systems :

Proprietary *AC*/Proprietary *AC*/*AC* 173/*AF* 23*H*
Proprietary *AC*/Proprietary *AC*/*AC* 173/*AF* 28*H*

attempted to simulate conditions on tests on old vessels.

(*c*) An exposure, made in the mid-summer of 1945, was allowed to dry out after a period of immersion. This test formed the raft control exposure for the *Marchioness of Graham* (4th Test), *see* p. 441.

The exposures for (*c*) above, were made on 15 × 10-in. panels and those for (*a*) and (*b*) as

TABLE XIII—*Raft Anti-Fouling Performance of Experimental Anti-Fouling Coat. Applied over a Proprietary Undercoat*

Paint Combination	Mean Wet Wt. of *AF* Applied, g./sq. m.	Fouling State after Exposure								Estimated *AF* Life, days
		15 days	30 days	60 days	94 days	119 days	151 days	182 days	209 days	
Prop./Prop./173/23*H* ...	72	*O*	*O*	*O*	*O*	*O*	*O*	*F*	*F*	165
Prop./Prop./173/28*H* ...	65	O_1	O_1	O_1/f	*f*	*f*	*f*	*F*	*F*	60
Dates of assessments (immersed 24th Oct., 1944 ; withdrawn 19th June, 1945)	Day	8	23	23	26	20	24	24	21	
	Month	xi	xi	xii	i	ii	iii	iv	v	

TABLE XIV—*Raft Anti-Fouling Performance of Complete Experimental Painting Systems, with Drying Out*

Paint Schemes	Mean Wet Wt. of *AF* Applied, g./sq. m.	Fouling State after Exposure						Estimated *AF* Life, days
		21 days	31 days	57 days	83 days	109 days	141 days	
AC 173/*AC* 173/*AC* 173/*AF* 23*H* ...	?	*O*	*O*	O_1	O_1	O_1	*f*	125
AC 173/*AC* 173/*AC* 173/*AF* 28*H* ...	?	*O*	*O*	O_1	O_1	O_1	*f*	125
Dates of assessments	Day	18	28	24	29	24	26	
	Month	vi	vi	vii	viii	ix	x	

These panels were immersed 28th May, 1945, and withdrawn after their assessment on 24th July and were allowed to dry out for four days. During that period the weather was fine and warm, and one face of each panel was exposed to bright sunshine for the greater part of each day. The panels were then re-immersed and were finally withdrawn on 20th Nov. 1945.

patch-painted applications (12 × 12-in.), on 24 × 24-in. panels. Details of the anti-fouling performance of these raft exposures are shown in Tables XII, XIII, and XIV.

Attention has previously been directed (in Table XI) to the use of the percentage of area rusted as the factor with the most influence on anti-fouling performance; in this respect these raft exposures were very satisfactory. For those panels continuously immersed the mean rusting estimate for any painting scheme after eight months' exposure did not exceed 2%, and even for those panels which were allowed to dry out during the course of their exposure the mean area rusted never exceeded 5%. However, it should be added that the painting schemes entirely composed of experimental paints blistered heavily after four months' exposure (mean estimates, 30–35%), and this led to subsequent extensive flaking. In contrast, blistering and flaking were virtually absent on the exposures made over a proprietary undercoat (*b*).

The results of these raft exposures suggest that the length of anti-fouling life of *AF* 23*H* and *AF* 28*H* was of the order of 130 and 110 days, respectively. The weight per unit area of these coatings which varied considerably, showed no correlation with length of anti-fouling life.

Leaching-rate determinations made on these anti-fouling compositions show that the rate of loss of poison was almost uniformly inadequate. Over a period of immersion of 240 days *AF* 28*H* had a copper leaching rate varying from 3·5–4·0γ/1000 sq. cm./day, *AF* 23*H* had a similar copper leaching rate for the first 70 days, which gradually rose to a maximum of 14γ/1000 sq. cm./day at 170 days, and thereafter decreased rapidly to 3 γ/1000 sq. cm./day, remaining at this value for the rest of the immersion period.

Discussion

The lack of correspondence between weight per unit area and length of anti-fouling life noted above, together with a knowledge of their inadequate leaching rates, indicate that the estimates of anti-fouling life given are fictitious in that they do not represent the length of time during which either of the compositions were able to offer protection against the settlement of all macroscopic fouling organisms. All they indicate is the length of time between exposure and the arrival of a major fouling settlement. The autumnal exposures (*a*) and (*b*) all failed during the barnacle settlement of April, 1945, and the summer exposures failed during the settlement period of *Tubularia* in September–October, 1945. In this connection it is interesting to note that some of the autumnal exposures acquired a little *Tubularia* fouling immediately after immersion, and it would therefore seem highly probable that, if exposure had occurred early in September instead of mid-October, both the test compositions would have fouled immediately.

The general conclusion to be drawn from these raft exposures therefore, is not that the length of life of the test anti-fouling compositions was too short (compared with the experimental prototypes), but that it did not exist; the exposures were only saved from fouling by the chance of their season of exposure.

It would appear, therefore, that any ship painted with these compositions, if exposed to fouling conditions of any intensity, should be found fouled when next it enters dry dock. The

service test on S.S. *Marchioness of Graham* (3rd test), although rated as unfouled following dockyard practice (*see* Table X), substantiates this statement. In this test it will be remembered that some settlement of barnacles had occurred. All of these barnacles were small (the largest size group was 1–2 mm. in length) and consequently could not be identified with certainty, but there was other evidence which indicated that they were *Balanus balanoides* and thus almost certainly represented part of the moderately heavy settlement of this species recorded at Millport during April, 1945. Although it is not certain that this settlement would have persisted (barnacles can settle and metamorphose on a surface too toxic for the persistence of the adult), their presence on the test compositions suggests that they were not proving effective. Thus a detailed examination showed the presence of fouling and indicated a very short anti-fouling life, in entire accord both with true raft performance and leaching-rate determinations.

This result is sharply contrasted to the test on S.S. *Marchioness of Graham* (2nd test) when, after a service period almost twice as long, both lay observation and detailed examination agreed that the hull was clean. The season of the year over which this test extended is clearly the over-riding factor in producing this result. The chances of settlement during the winter in the Clyde are sufficiently small to render it quite impossible during this period to assess the performance of an anti-fouling composition. Experiences of service tests in these waters and raft exposures at Millport both suggest that, if it is intended to dry-dock a ship both in the late autumn and in the early spring, it is quite unnecessary to apply an anti-fouling composition at the autumn dry-docking.

Seasonal conditions were clearly different for the remaining test on this vessel (S.S. *Marchioness of Graham* (4th Test)) which extended from May to the following February. In this case the non-toxic control patches were fouled with a variety of plants and animals, but the patches to which *AF 23H* and *AF 28H* had been applied would not have been considered as fouled following dockyard practice. The presence of *Ectocarpus*, revealed by detailed examination, indicates that the compositions have ceased to offer full protection. It should be added that most of the types of organism found on the non-toxic patches are very sensitive to copper and the fact that they did not occur on the toxic patches is in agreement with the known leaching rates of the experimental compositions used which, though not sufficiently high to prevent settlement of the critical fouling organisms, were high enough to prevent settlement of very sensitive forms. The small size of the *Ectocarpus* on the toxic patches suggests, at first sight, that settlement had occurred shortly before dry-docking, indicating an anti-fouling life of the order of $4\frac{1}{2}$ months (*i.e.*, neglecting the winter period, October to February). Even this interpretation may not be valid since it neglects the tendency, frequently observed on raft-exposed panels, for *Ectocarpus* to die down in the autumn so that the small plants revealed by microscopic examination may thus represent an earlier, more luxuriant growth. If this were so the estimate of the effective anti-fouling life would have to be considerably reduced, thus bringing it closer to those of the previous two tests.

The next three tests (M.V. *British Might*, S.S. *Empire Bromley*, and S.S. *Empire Lewisham*) were all rated as unfouled following dockyard practice. The conditions of service for all three vessels were not such as to suggest that heavy fouling settlement was likely. The M.V. *British Might* had berthed in the Manchester Ship Canal (where the salinity is low and the water contains industrial effluents) when in this country, and this would tend to kill and remove any fouling which might have settled. The other two vessels were coasters, for both of which port visits were short and entry into fresh water, or water of low salinity, frequent. The unfouled condition of the experimental anti-fouling compositions is thus no guide to their performance.

That no anti-fouling action remained is indicated by the results of the analyses. For *AF 23H*, 95% of the contained copper had been lost, and other considerations suggest that the paint had for some time contained negligible amounts of copper. This further substantiates the thesis expressed at the end of the preceding paragraph.

TABLE XV—*Details of Anti-Fouling Paint Applied to S.S.* Marchioness of Graham

Composition	Mean Wt. per Unit Area, g./sq. m.	Copper Content, g./sq. m.
AF 276M	247	92
AF 277M	197	86
AF 278M	216	108

TABLE XVI—*Details of Anti-Fouling Paint* AF *288*M *Applied to S.S.* Marchioness of Graham

Patch	Mean Wt. per Unit Area, g./sq. m.	Copper Content, g./sq. m.
1	442	221
2	297	148
3	167	83

The S.S. *Pandorian* is the sole member of this series of tests which would be rated as fouled, both according to dockyard practice and according to the more severe test afforded by detailed examination. In contrast with the three tests just discussed, where lack of settling stages had not allowed the anti-fouling life to be correctly estimated, this test is equally inconclusive for different reasons. Since this test was the longest in the series, fouling of the experimental compositions was perhaps to be expected, but even so, differences between the non-toxic control areas and the toxic areas might have enabled some estimate of the length of anti-fouling life of the test compositions to be made. Unfortunately, the long stay in the Manchester Ship Canal midway through the service period probably obliterated this early evidence and thus the general similarity between the fouling on the non-toxic and toxic patches, suggesting a negligible anti-fouling life although in agreement with the deductions which have been drawn from the leaching rate data, is purely fortuitous.

TABLE XVII—*Fouling on Test Areas of S.S.* Marchioness of Graham (*6th Test*)

Patch	Fouling Organisms Present	Fouling State
1	No macroscopic fouling; a greenish slime present which contained a filamentous green alga, possibly *Ulothrix*	Unfouled
2	Condition as on Patch 1	Unfouled
3	The greenish slime present on Patches 1 and 2, was also present on this patch, together with traces of the brown seaweed *Ectocarpus*	Unfouled
Non-toxic control patches	The green weeds *Enteromorpha* and *Ulva* had settled in some numbers, particularly near the water-line. A little *Ectocarpus* was present and traces of red weeds, *e.g.*, *Ceramium*, also occurred. Tube-worms (*Pomatoceros*) 1–2 cm. long were present, and there had evidently been two settlements of barnacles, a smaller settlement which had occurred earlier (individuals 10 mm. in diameter on dry-docking) and a larger settlement which had occurred just before dry-docking (1 mm. in diameter on dry-docking).	Fouled

Later Service Tests

Subsequent experimental work indicated that cuprous oxide compositions containing a high proportion of this poison (of the order of 50% by weight in the wet paint film) were more likely to give a satisfactory anti-fouling performance for longer periods than the compositions tested earlier. Service tests were therefore carried out using the more promising compositions of this type ; all were made on Clyde passenger vessels and thus were comparatively short tests, made on ships operating in coastal, temperate waters.

Two of these tests (S.S. *Queen Mary II*, 281 days ; S.S. *King Edward*, 178 days) gave no useful information, as their routine involved berthing each night in fresh water. The experimental anti-fouling compositions (*AF* 278*M*, *AF* 288*M*, and *AF* 293*M* for S.S. *Queen Mary II* and *AF* 283*M*, *AF* 288*M* and *AF* 337*M* for S.S. *King Edward*) and the non-toxic control areas were unfouled.

S.S. Marchioness of Graham (*5th Test*)

Patches of *AF* 276*M*, *AF* 277*M*, and *AF* 278*M* were applied over the proprietary undercoat used generally over the hull, a non-toxic patch also being included in the test area on each side. The weights of anti-fouling paint per unit area are given in Table XV.

The vessel entered dry dock again on 17th April, 1946, 62 days after the experimental compositions were applied. When inspected, all the toxic patches were unfouled and the non-toxic control areas were only lightly fouled. Paint condition was very good.

S.S. Marchioness of Graham (*6th Test*)

This test immediately followed that just described, and in it *AF* 288*M* was applied at three different weights per unit area. Details of these are given in Table XVI.

The test extended from 27th April until 8th October, 1946, a total of 164 days. The fouling present on the test areas is detailed on Table XVII.

From these results it is evident that all three patches had offered complete protection against the settlement of macroscopic fouling organisms throughout the service period. Although traces of *Ectocarpus* were recorded on patch 3, it should be noted that the paint on this patch was evidently capable of offering protection against the barnacle settlement which had been encountered, to judge from the non-toxic patches, just before dry-docking took place.

General Discussion

Although no information can be gained from the two tests of high cuprous oxide compositions

TABLE XVIII—*Leaching Rates and Anti-Fouling Lives for Compositions Used in Later Service Tests*

Composition	Leaching Rate[a] after Soaking, days											Mean Wet Wt. of *AF* Applied (raft exposure), g./sq. m.	Estimated *AF* Life, days
	3	10	21	41	56	71	95	114	149	172	194		
AF 276*M*	62·8	41·1	26·0	39·4	39·1	16·6	12·6	13·2	10·7	9·2	8·6	132	195
AF 277*M*	54·8	35·4	17·1	38·6	46·3	19·6	12·8	12·5	9·9	9·6	9·1	145	160
AF 278*M*	34·8	30·1	20·7	34·9	46·1	15·3	13·2	13·7	15·2	11·1	12·5	206	>240
AF 288*M* (1) ...	13·7	10·1	?5·4	27·1	14·8	11·2	12·2	12·2	11·8	9·3	10·2	254	>240
AF 288*M* (2) ...	14·9	14·9	14·3	9·1	12·1	...	29·4	...	14·3	12·2	9·3	...	...

a ... mg. copper/sq. cm./day

which were made on vessels which berthed in fresh water (S.S. *Queen Mary II* and S.S. *King Edward*), the remaining two tests gave reliable data. Since the non-toxic patches were fouled on S.S. *Marchioness of Graham* (5th Test) and since this fouling had almost certainly settled shortly before dry-docking, adequate protection had been afforded by the anti-fouling compositions for the whole period of the test. The remaining test on S.S. *Marchioness of Graham* emphasized the value of non-toxic control patches in enabling a true estimate to be made of the paint performance. Composition *AF* 288*M*, at all weights per unit area, had afforded protection against fouling settlement up to the time of dry-docking, a total period of 164 days.

Summary and Conclusions

In order accurately to assess the performance of an anti-fouling composition under service conditions it is essential to take into consideration the route, the ports of call, the periods in port, the total period of service and their relation to seasonal conditions. If all of these are known and are considered together with chemical data concerning original composition and poison loss, a reliable estimate of performance can usually be made. This can be done even if the test has been carried out in temperate waters if due account is taken of the seasonal nature of fouling settlement under such conditions, and when dockyard inspections can be supplemented by detailed microscopic observations, and can also be interpreted in the light of biological knowledge gained from raft experience. There are, however, circumstances, *e.g.*, docking in fresh water and very long service periods, which can vitiate any test. Superficial comparisons of anti-fouling performance and any one of its controlling factors can lead to entirely false conclusions, resulting in fictitious estimates of the compositions tested.

ACKNOWLEDGMENTS

Clearly the work described in this paper has involved the help of a number of people, in either an official or a practical capacity. This series of tests was initiated by Professor J. E. Harris, and we wish to acknowledge his advice and criticisms throughout.

Dr. M. F. Mare (Mrs. G. M. Spooner) was responsible for the reconstruction of the fouling history of the test made on S.S. *Bellerophon*, and we are much indebted to her for this assistance.

A number of acknowledgments to shipping companies have already been made ; we would, however, particularly wish to thank Mr. C. Gordon Smith of Messrs. Alfred Holt and Co., and Mr. C. A. Bremner, until recently, Marine Superintendent (Scotland) for the L.M.S. Railway Co. For the supervision of the preparation of some of the paints we are indebted to Mr. F. Fancutt of the Scientific Research Department, the L.M.S. Railway Co., Derby.

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IRON AND STEELWORKS ENGINEERING

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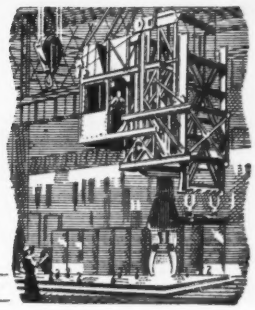


DESCRIPTION OF NEW PLANT

The Light-Section Mill at the Darlington Works of the Darlington and Simpson Rolling Mills, Ltd.

Introduction

WHEN it was decided by the Management of the Darlington and Simpson Rolling Mills, Ltd., to instal additional plant, careful consideration was given to the best location for a modern mill, bearing in mind the sources of supply of raw materials and the costs of fuel, water, and transport; other matters, such as centralizing the control of the Company's works in one area, had also to be taken into account. It was finally decided that the new plant should be located at Darlington, where the Company already had existing works. The site chosen was close to the existing works but on the opposite side of the main-line railway, and the layout of the plant is such that future extensions can be made.

Although the Company's rolled products cover a wide range of small sections the new plant is intended to meet an increasing demand for standard window-frame sections. At the same time, however, provision had to be made for the production of other, similar, small shapes. The plant in its final form is the result of close study and co-operation between the technical staff of the Darlington and Simpson Rolling Mills, Ltd., and the Company's consulting engineers (The International Construction Co., Ltd.). The mill equipment was designed and supplied by The Brightside Foundry and Engineering Co., Ltd.

The new mill, which was completed and put into operation at the beginning of this year, was designed for an average output of 75 tons per shift but has at times considerably exceeded this tonnage. It is capable of rolling sections with very accurate finished dimensions.

Site Preparation and Buildings

The site preparation involved a considerable amount of levelling, and a complete drainage system had to be put in from the site to the town drains in the main road. A new access road 18 ft. wide and about 1700 ft. long was laid down to connect the new works to Whessoe Road, and new sidings and service tracks having an approximate total length of 2800 yards were also installed; a new locomotive was introduced to deal with incoming and outgoing traffic.

The main building is 1000 ft. long by 100 ft. wide, with closed side walls having continuous glazing; lighting is also provided by continuous lines of glazing in the roof. This building is served by one 15-ton crane and two 5-ton cranes. The billet yard, which is 100 ft. wide and 400 ft. long, is located parallel to the main building and is served by one 10-ton overhead crane. The general layout of the whole plant is shown in Fig. 1.

Raw-Material Handling

The raw material for the mill, in the form of billets, is received by rail tracks running the length of the billet yard and is handled by the 10-ton electric overhead crane. The billets, which are in lengths of about 30 ft., are lifted from stock or from rail on to a grid ramp, from which they are fed by roller gear to a 450-ton Scriven shear. This shear is capable of cold-cutting one $3\frac{1}{2}$-in.

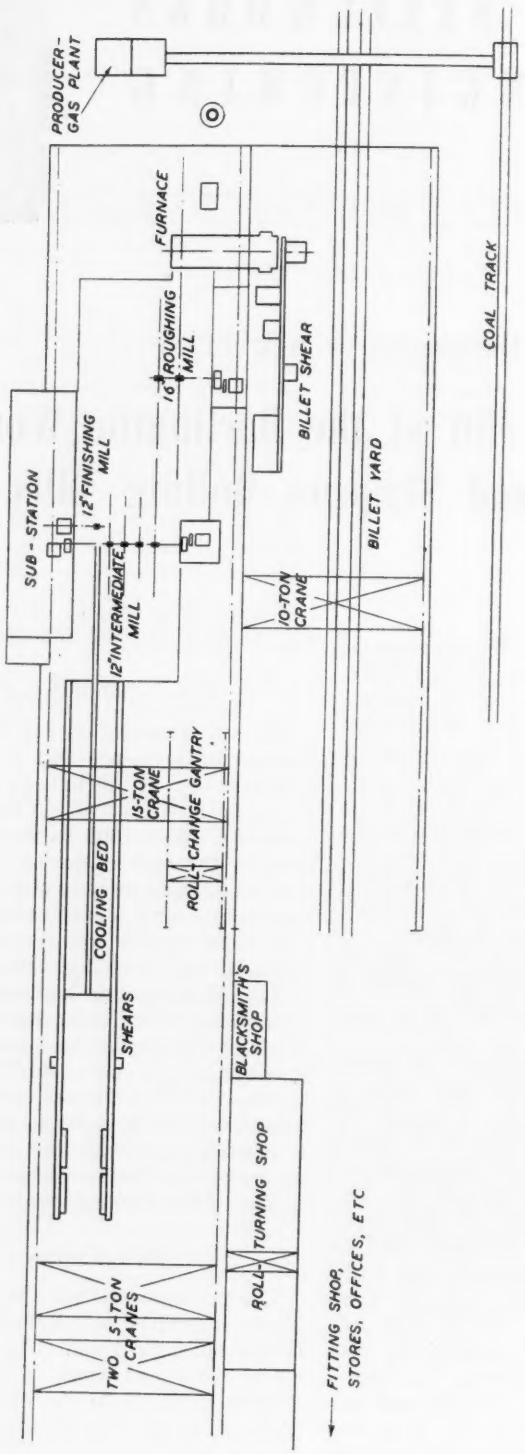


FIG. 1—Layout of light-section mill

square billet or three 2-in. square billets simultaneously. The cut billets can be passed on by roller gear to the furnace or, if desired, can be discharged from the roller gear into collecting pockets for taking away to stock. At the side of the pockets is located a short grid ramp for reloading cut billets from stock on to the roller gear in front of the furnace.

Continuous Billet Furnace and Ancillary Equipment

An electrically operated pusher passes the billets from the roller gear into the furnace. The pusher is designed to operate either one row of full-length billets or two rows of short billets, as desired. The heated billets are discharged from the furnace by an electrically operated push-out gear. The operator, who is stationary, has a view of the billets in front of the furnace discharge door, and he is able to discharge one billet at a time as often as required, on receiving a signal from the mill.

The furnace is shown in Fig. 2, and is designed to achieve an output of from 12 to 15 tons/hr. with a hearth 50 ft. long and 14 ft. wide. It is provided with hearth skids and is fitted with a suspended type of arch. Producer gas is used for firing, and the air for combustion is preheated in a needle-type recuperator, the hot air passing through a duct to Typhoon rotary flame burners. The producer gas is supplied from a 10-ft. Morgan producer-gas-machine plant installed just outside the mill building. The machine has an overhead coal bunker of about 50 tons capacity, the coal being brought to this bunker by a belt conveyor from a ground bin into which the coal is fed from drop-bottom coal wagons. The gas passes from the gas machine through a dustcatcher and horizontal gas main to an underground flue leading to the furnace burners. A boiler for supplying steam to the gas plant is located adjacent to the gas machine. A 4 ft. 6-in. dia., 120-ft. high chimney is provided for the waste gases from the furnace.

Roughing and Intermediate Stands

The roughing mill consists of two 16-in. three-high stands fitted with rolls having a barrel length of 3 ft. 6 in. The stands are mounted on a common bedplate and are driven by a 750-h.p. D.C. motor, through a reduction gear. The high-speed shaft of the gear-box is fitted with a flywheel having a stored energy of 10,000 h.p.sec. at 800 r.p.m., carried between the gear-box and a separate outboard bearing. Separate lubricating pumps are provided for the gear-box and the mill pinion housing. The mill is shown in Fig. 3, and details of mill speeds are given in Table I.

The roughing mill is located with its centre-line 64 ft. 9½ in. from the centre of the furnace, the first stand being in line with the discharge doors. The billets discharged from the furnace are fed on rollers to the first roughing stand. Tilting tables are provided behind both stands, and skid gears are located in front of and behind the roughing mill for moving the billets from the first to the second stand. The incoming and outgoing rollers for the roughing mill are 12 in. in dia. and are driven by 1-h.p. individual motors giving a peripheral speed of 455 ft./min. All the rollers run on roller bearings. For certain sections repeaters are used on the second roughing stand, and for these sections the billet leaves the furnace, enters and leaves the roughing stand, and is delivered to the intermediate mill without any handling.

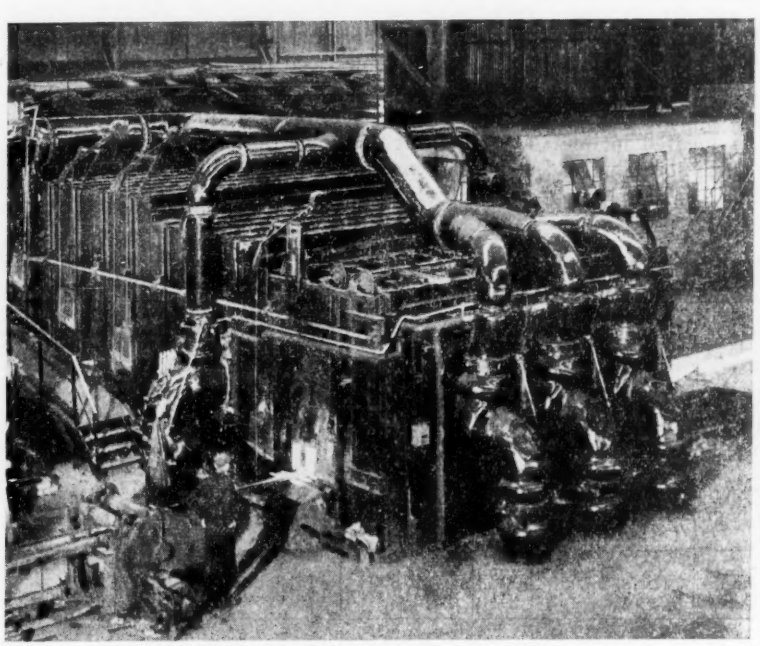


FIG. 2—Continuous billet furnace and roughing mill

The intermediate train of mills (*see* Fig. 4), is located with the first stand in line with the second roughing stand and at a distance of 85 ft. from it. This intermediate train consists of four stands in line, three

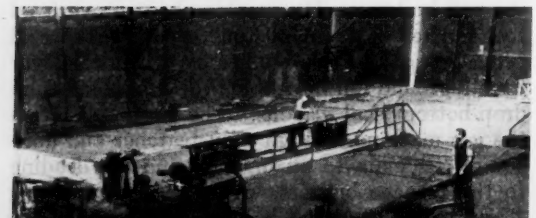


FIG. 3—Roughing mill, outgoing side

driven from one end and the fourth driven separately from the opposite end.

The first stand comprises a three-high set-up, but with rolls for bottom pass only; the second stand is three-high with rolls for top pass only, and the third stand is two-high. These three stands have rolls 12 in. in dia. and 30 in. long, and are driven by one 600-h.p., D.C. motor, through a reduction gear. The high-speed shaft of this gear is fitted with a flywheel having a stored energy of 12,000 h.p.sec. at 800 r.p.m. The fourth intermediate stand is located in line with these three and consists of a pinion housing and a single two-high 12-in. stand with rolls 18 in. long and driven by a 600-h.p. D.C. motor through a reduction gear.

Finishing Mill and Cooling Bank

The finishing mill is set back from the intermediate train and consists of a pinion housing and a single two-high stand with 12-in. dia. × 18-in. long rolls directly driven by a 450-h.p. D.C. motor. In view of the need for accurate rolling the mill housings are of the closed-top type. The 7-in. dia. roll necks are carried in Skefko roller bearings, with accurate means of adjustment.

The bearing assemblies are carried in cast-steel chocks fitting accurately into the mill housings and arranged to take the side thrust involved in the rolling process. The top rolls are spring-balanced from the housing tops and are adjusted vertically by hand through forged-steel screws in phosphor-bronze nuts. The bottom rolls are adjusted vertically by means of wedges operated by screws and tommys. The coupling spindles between the mills are of the Universal type and permit easy withdrawal when changing the mill stands. The mill controls are housed in enclosed cabins which are raised above the mill-floor level to give the operators a clear view of the mills and mill floor.

The run-out chutes behind each stand are fitted with individually driven rollers. From the finishing stand a roller table leads to a double-sided Morgan-type cooling bed 160 ft. long, the bars being automatically thrown off from the incoming roller table on to the cooling bed, which traverses the bars to roller tables on each side of the bed.

The roller tables feed the bars to shears which are able to cut up to four bars simultaneously. A measuring device with a lifting-stop is fitted at each shear to enable the bars to be cut to any required length. Crop ends falling from the shear pass into bins in pits in front of the shear, the

TABLE I—*Mill Data*

	Stands	Roll-Barrel Length	Drive, h.p.	Motor Speed, r.p.m.	Mill Speed, r.p.m.	Delivery Speed, ft./min.	Flywheel Energy Storage, h.p.sec. at 800 r.p.m.
Roughing mill	Two 16-in. 3-high	3 ft. 6 in.	750	400–800	65–130	275–550	10,000
Intermediate stands	Two 12-in. 3-high	2 ft. 6 in.	600	400–800	125–250	390–780	12,000
	One 12-in. 2-high	2 ft. 6 in.	600	400–800	125–250	390–780	
	One 12-in. 2-high	1 ft. 6 in.	600	400–800	175–350	550–1100	...
Finishing mill	One 12-in. 2-high	1 ft. 6 in.	450	175–350	175–350	550–1100	...

bins being transported by the overhead crane when full.

The cut bars from the cooling-bed shears pass on roller tables to four sets of pockets, two on either side of the cooling bed. The bars are pushed off the roller table into the pockets, which are carried on weigh tables. The four weigh tables are connected to one weighing-machine dial so that the operator can register the weight of finished bars off-loaded.

At the finishing end of the mill building, roller straightening machines, shears, and other finishing equipment are installed, and the building provides ample stocking space for finished bars. The bars from the straightening machines are stacked as ejected into neat piles providing easy handling and ensuring economy of space for storing and transport. This end of the building is served by two 5-ton overhead cranes, and a railway loading dock 370 ft. long is provided at the end of the stocking bay.

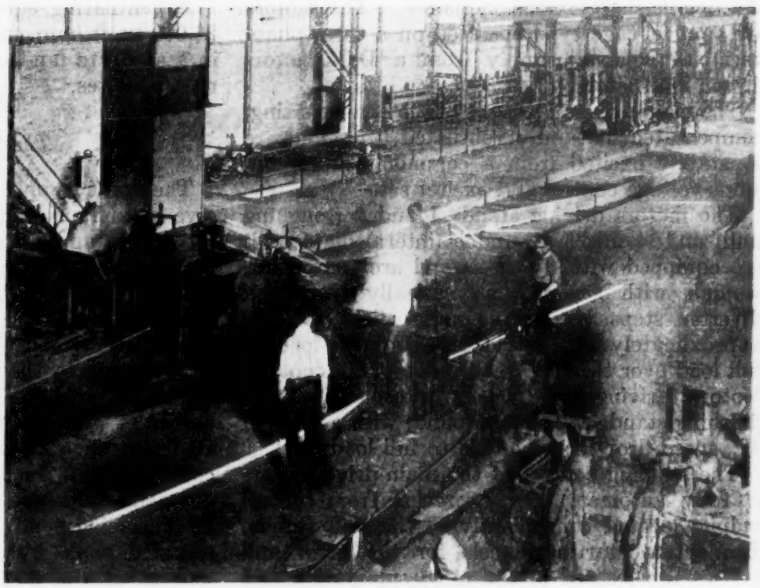


FIG. 4—The 12-in. intermediate and finishing mills

Ancillary Equipment

A 100-ft. long, 30-ft. span, gantry serving a 2½-ton crane is located in the main mill bay, beneath the main crane runway. This gantry encloses the area used for setting-up and fitting the change-roll stands. Rolls are taken to and brought from the roll-turning shop by means of a narrow-gauge track, by the side of which the stands are set up with new rolls and guides so that the completed stand can be rapidly transferred to the mill by the 15-ton mill crane when changing the rolls.

Adjoining the main building are the ancillary buildings comprising blacksmith's shop, roll-turning shop, guide and fitting shops (fitted with modern types of machinery), offices, stores, canteen, and first-aid departments. The roll shop, at present fitted with three Brightside roll lathes, is served by a 2½-ton electric overhead crane and is light and roomy.

Electrical Equipment

The bulk power supply to the plant is obtained from Darlington Corporation at 6200 V. All the main-drive motors, the major auxiliary motors, and the cranes are operated on constant-voltage D.C. at 460 V., the conversion from the bulk A.C. system being through two 900 kW. rotary converters. Rotary converters were selected for conversion in preference to mercury-arc rectifiers on the grounds of better inherent voltage-regulation characteristics and the ability to absorb the regenerative feed-back required under some conditions of operation without the complications required for similar characteristics on rectifier equipment.

Auxiliary drives with constant-speed and constant-running characteristics are in general operated on the 400-V., three-phase, 50-cycles, A.C. system.

The mill tables have individual-motor-driven rolls, each roll being driven from an overhung direct-coupled squirrel-cage motor operating on a three-phase, 16-cycles, A.C. supply from a motor alternator set common to all tables. The table rolls forming a particular group are operated as one unit by means of master reversing contactors. Individual protection is provided for each table roller motor, with facilities for readily isolating any motor. Roller-table speeds are designed for the mean rolling speed of the relative mill stand within the limits imposed by standardization of roller sizes and fixed frequency of power supply to the roller motors.

The run-on rollers to the double-sided Morgan cooling bed are individually motor driven, the rollers in this case being overhung on each side of

the double-shaft extension motor. The motors are squirrel-cage type operated on a three-phase variable-frequency supply from a D.C. motor-driven alternator.

The main-drive motors are of the non-reversing, compensated, naturally ventilated type, and are separately excited from a common 230-V. constant-voltage control and exciter set.

The motors driving stands 1 and 2 (roughing mill) and stands 3, 4, and 5 (intermediate mill) are equipped with flywheels and are compound-wound, with several automatically controlled diverter steps across the series field to give approximately 15% speed drop from no-load to full load over the full speed range of the motors. Motors driving the fourth intermediate and finishing stands are shunt-wound, with a limit of 3% speed drop from no-load to full load.

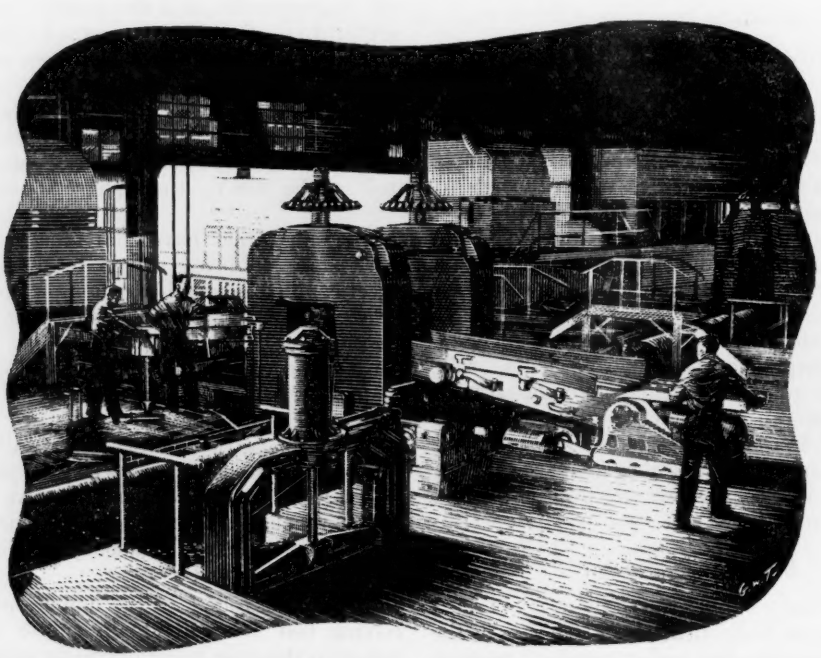
The starting control of the main-drive motors is fully automatic, for operation from control pulpits located conveniently to the mill stands. The actual starting panels for the main mill motors are located in the main sub-station and form an integral part of the main 460-V. D.C. distribution board. The main sub-station includes, in addition to the finishing-mill drives, two rotary converters and the main incoming and feeder switchboard panels.

A ventilating equipment comprising a fan of 25,000 cu. ft./min. capacity and a filter is provided in a separate fan house for supplying air to the motor houses.

The Water Supply

The water supply for the plant is arranged to give maximum economy. Clean water is raised by a 75 gal./min. capacity pump to a tank about 50 ft. above ground level and is used at the gas plant and in the boilers. As much water as possible is recirculated in a closed clean-water system, the small amount not recovered in this way passing to the mill system. Water used in the mill is circulated from an elevated tank giving an outlet pressure at the rolls of approximately 30 lb./sq. in. All the water used in the mill is collected in a sump served by two pumps of 500 gal./min. capacity and returned to a 70 ft. × 50 ft. cooling pond, from which it is lifted to the elevated tank by two automatically operated pumps, each of 500 gal./min. capacity.

Provision is made for the mill scale to be washed through passages in the mill foundations to a scale pit, located in the billet yard, where the scale settles. The pit is cleaned out regularly, and the water is recirculated through the mill system.



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Joint Meeting in Manchester

A joint meeting of the Manchester Metallurgical Society with the Iron and Steel Institute and the Institute of Metals will be held on Wednesday, 26th November, 1947, at 6.30 P.M., in the Engineers' Club, Albert Square, Manchester.

Mr. E. W. Colbeck, of Messrs. Hadfields, Ltd., Sheffield, will read a paper on "*Some Metallurgical Problems in the Field of Atomic Energy*," and Dr. L. C. Bannister, President of the Manchester Metallurgical Society, will be in the Chair.

Jernkontoret 200th Anniversary Celebrations

The Swedish Ironmasters' Association, Jernkontoret, celebrated the 200th Anniversary of its foundation in Stockholm from 5th to 12th September, 1947. A number of distinguished foreign guests attended, including representatives of the United States of America, Canada, France and Switzerland, and of Denmark, Finland and Norway. The Council of the Iron and Steel Institute was represented by the President, Dr. C. H. Desch, F.R.S. (and Mrs. Desch), Mr. Arthur Dorman, Past-President (and Mrs. Dorman) and the Secretary, Mr. K. Headlam-Morley; and the British Iron and Steel Research Association by the Director, Sir Charles Goodeve O.B.E., F.R.S., who was accompanied by Lady Goodeve. As Sir John and Lady Duncanson, who had accepted invitations, were unable to attend, Mr. Dorman acted also as a representative of the British Iron and Steel Federation.

Dr. Desch presenting Bessemer Gold Medal to Dr. Magnus Tigerschiöld.

The Celebrations opened with the Jubilee Meeting of Brukssocieteten (the Ironmasters' Association) in the Assembly Hall of Jernkontoret, when addresses of congratulation and good wishes were presented by representatives of Swedish and foreign Institutions. Dr. Desch, on behalf of the Council of the Iron and Steel Institute, presented to Jernkontoret a complete set of specially bound volumes of the *Journal* from 1869 to 1945, together with the Carnegie Scholarship Memoirs and Special Reports. Dr. Desch also presented the Bessemer Gold Medal to Dr. Magnus Tigerschiöld, Director of Research of Jernkontoret, in recognition of his distinguished services to the Swedish iron and steel industries and as part of the Institute's tribute.

On the following morning the new buildings of the Metallographic Institute (Director: Professor Eric Rudberg), were opened by the Crown Prince of Sweden and in the evening the main celebrations took place in the Town Hall. After an address by the Chairman of the Board of Directors of Jernkontoret, Bruksdisponent Helge Silverstolpe, medals were presented by the Crown Prince to six workmen and foremen with long service in Swedish steelworks. A banquet, attended by about 600 guests, was held in the Golden Hall and was followed by a display of Swedish gymnastics and a dance in the Blue Hall.

Following the Celebrations in Stockholm a number of foreign visitors, accompanied by Mr. Gosta Frisell, Director, and other officials of Jernkontoret and their wives, were taken on a tour of iron and steel works and other places of interest in Central Sweden.

It is hoped to give further details of the work of Jernkontoret and the Metallographic Institute in a later issue of the *Journal*.

Society of Instrument Technology

Local Members of the Iron and Steel Institute were invited to attend the first meeting of the new session, held by the Tees-side Section of the Society of Instrument Technology at the Cleveland Scientific and Technical Institute, on Wednesday, 15th October, 1947.

The lecture was given by Mr. J. A. Hall, of the

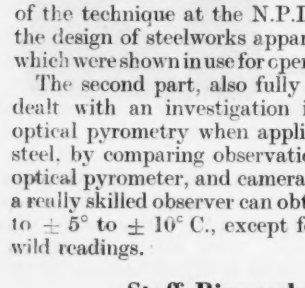
National Physical Laboratory, who spoke on "*Liquid Steel Temperature Measurement.*" The paper was given in two parts, each illustrated by a film.

The first part was concerned with the development of a special thermocouple for obtaining temperatures of liquid steel in a bath. The accuracy obtained is of the order of ± 5° C. at temperatures in the neighbourhood of 1600° C. The film showed the development of the technique at the N.P.L. and various stages in the design of steelworks apparatus, different forms of which were shown in use for open-hearth furnace control.

The second part, also fully illustrated by the film, dealt with an investigation into the limitations of optical pyrometry when applied to streams of liquid steel, by comparing observations with thermocouple, optical pyrometer, and camera. The results show that a really skilled observer can obtain results reproducible to ± 5° to ± 10° C., except for occasional obviously wild readings.

Staff Biography No. 11

Mr. R. A. RONNEBECK was born in Middlesbrough in 1898 and was educated at Middlesbrough High School. After leaving school he began a commercial career in a local merchant's office, but left in 1916 for three years' service with the Royal Artillery. On demobilization he went to Sweden where he spent two years working for a Swedish coal importer and shipowner; during this period he also studied Anglo-Swedish trading conditions, and became fluent in the Swedish language. Later, for a short period he studied in Hamburg, and then returned to this country where, in partnership with his brother, he traded as an exporter of British iron and steel products. Mr. Ronnebeck was also actively interested in the Middlesbrough Salvage Co., Ltd., but the Company's activities were seriously affected by the conditions obtaining in 1932–1933, and Mr. Ronnebeck joined Imperial Chemical Industries, Ltd.



After a short period in the I.C.I. hydrogenation plant at Billingham-on-Tees, Mr. Ronnebeck was transferred to the Company's Library staff as Abstractor. In 1937 he obtained a more responsible position in the Technical Record Department of the Bristol Aeroplane Co., Ltd., and then in the following year joined the staff of the Iron and Steel Institute, again as Abstractor. He is now largely concerned with the Institute's Translation Service. He is a member of the Royal Institute of International Affairs, and of the Newcomen Society. It may be of interest to know that his grandfather, the late Mr. Edward Crowe, was elected a member of the Institute at its First General Meeting, held in Middlesbrough in 1869.

NEWS OF MEMBERS

▶ Mr. J. L. ASTON is now at Sheffield University where he will carry out research on the rapid heat-treatment of steel, particularly from the point of view of the metallurgy of the induction hardening of steel.

▶ Mr. M. K. HALDAR has left the Research Department of the London, Midland and Scottish Railway Company, Derby, and is taking up a special course on industrial and engineering radiography, under the auspices of Kodak, Ltd., Harrow, Middlesex.

▶ Mr. H. G. HOSKINS has taken up a position with the Aluminium Company of South Africa, Natal.

▶ Mr. P. W. HYDE has joined the Research Laboratories of the General Electric Co., Ltd., Wembley, Middlesex.

▶ Dr. R. JACKSON has left the Research Department of Messrs. Hadfields, Ltd., Sheffield, and has taken up a position with the British Coal Utilization Research Association, Leatherhead, Surrey.

▶ Mr. I. MANNING has been appointed Assistant Technical Officer (metallurgy) with I.C.I. Ltd., Billingham Division.

▶ Mr. P. A. MORGAN has taken up a position with the Research Department of I.C.I. Ltd., Metals Division, Birmingham.

▶ Mr. D. RIST has left Messrs. Guest Keen and Baldwins Co., Ltd., Cardiff, and has returned to his permanent address at Messrs. Dorman, Long & Co., Ltd., Redcar.

▶ Mr. H. H. ASCOUGH has relinquished his position as Steelworks Manager at the Redcar Works of Messrs. Dorman, Long & Co., Ltd., having been appointed Assistant Works Manager at the Port Talbot and Margam plants of the Steel Company of South Wales, Ltd.

▶ Mr. H. J. MERCHANT is leaving Messrs. John Garrington & Sons, Ltd., Bromsgrove, on 20th November, to return to the Australian Forge and Engineering Pty., Ltd., Sydney, N.S.W., as Chief Inspector and Metallurgist.

▶ Mr. H. KNIGHT has left Sun Engineering (Crowle) Ltd., and has taken up an appointment with Tractor Spares, Ltd., Wolverhampton.

▶ Mr. K. C. CHOUDHURI has joined the Metallurgical Laboratory, as Chemist and Metallurgist, at Locomotive Works, E.I. Railway, P.O. Jamalpur, Dt. Monghyr, India.

▶ Mr. BERTON H. DELONG has been promoted to the position of Vice-President and Technical Director of the Carpenter Steel Corporation, Reading, Pa., U.S.A.

▶ Mr. R. J. BARHAM has returned to his Argentine address at Departments Mecanico B.A.P., Junin (B.A.) Argentine.

▶ Mrs. E. F. DUNLOP has returned to The Hong Kong Electric Co., Ltd., North Point, Hong Kong.

▶ Mr. R. C. WILLIAMS has changed his business address to New Metals and Chemicals, Ltd., 16, Northumberland Avenue, W.C.2.

▶ Mr. A. R. O. BISHOP has changed his business address to Ingeniero Aceristu de la S. H. Mieres, Aportado, 20-Mieres, Asturias, Spain.

▶ Mr. H. F. JOHNSON has changed his address to S.Q. 851/4 Palm Grove, c/o A.I.O.S. Abadan, South Iran.

Elections

▸ Mr. L. H. COOPER, a Director of the Mond Nickel Co., Ltd., has been elected Assistant Secretary and Assistant Treasurer of the International Nickel Company of Canada, Ltd.

▸ Mr. A. T. GREEN, O.B.E., Director of Research of the British Refractories Research Association and the Pottery Research Association, has been unanimously appointed to the office of Honorary General Secretary of the British Ceramic Society in succession to the late Dr. J. W. Mellor.

▸ Mr. J. H. JOLLY has been elected Chairman of Messrs. Guest Keen and Nettlefolds, Ltd., in place of Sir Samuel R. Beale who has retired but retains his seat on the Board.

Awards

▸ Mr. W. D. BIGGS has been awarded the degree of B.Sc. with Honours in Metallurgy, by the University of London.

Memoranda

▸ The IRON AND STEEL COMPANY OF NEW ZEALAND, LTD., have now opened their London office at 6, Broad Street Place, E.C.2.

▸ The postal and registered office of the FULLERS' EARTH UNION, LTD., is now at Patterson Court, Nutfield Road, Redhill, Surrey.

Obituary

The Council regret to record the deaths of :

Mr. GAVIN COWPER, London Manager of Messrs. Colvilles, Ltd., on 9th October, 1947.

Mr. A. W. LEE, Fuel Engineer at Messrs. John Lysaght & Co., Ltd., Scunthorpe, in July, 1947.

Mr. D. H. HEWITT, Research Manager of Messrs. Lewis Berger & Sons, Ltd., on 25th August, 1947.

Capt. J. F. LUCKMAN, Director and Consultant, Messrs. Latch and Batchelor, Ltd., Birmingham.

CONTRIBUTORS TO THE JOURNAL

George V. Slottman, Ph.D.—Manager, Technical Sales Division, Air Reduction Company, New York. Dr. Slottman received his early technical training at the Massachusetts Institute of Technology and gained his B.S. degree in 1925. In 1927 he received the degree of Ph.D. of the University of Berlin. From that year until 1930 Dr. Slottman was Professor of Chemical Engineering at the Massachusetts Institute of Technology and also Director of the Buffalo Station School of Chemical Engineering Practice, at the Lackawanna plant of the Bethlehem Steel Company.

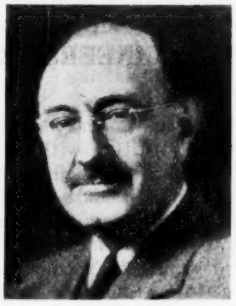
In 1930 Dr. Slottman came to England, and for four years held the position of Chief Combustion Engineer and Ironworks Manager at the United Steel Companies, Ltd., Sheffield. He returned to America in 1934, when he took up his present appointment. Dr. Slottman specializes in combustion in metallurgical processes and the application of oxygen to metallurgical problems.

John Nortcliffe, B.Sc.—Physicist at the Brown-Firth Research Laboratories, Sheffield. Mr. Nortcliffe was born in 1926, receiving his education at an elementary school and at the High Storrs Grammar School. In August 1942 he joined the Midland Coke Research Committee, working under Dr. R. A. Mott as a laboratory assistant. In 1943 Mr. Nortcliffe received from the Sheffield Education Committee a University Entrance Scholarship to Sheffield University, and he obtained the B.Sc. degree in 1945.

Since taking up his present appointment at the Brown-Firth Research Laboratories, Mr. Nortcliffe has been engaged in work on high temperatures and on transformation temperatures in steels.

Kenneth J. Irvine, B.Sc.—Educated at Latymer's School, Edmonton, Middlesex, and at Leeds University, where he obtained a First Class Honours Degree in Metallurgy, Mr. Irvine was engaged in research work for the Ministry of Supply until 1945 when, at the age of 21, he was appointed Assistant Lecturer in Metallurgy at Leeds University.

Early in 1947 he was awarded a Travelling Post-Graduate Scholarship under the Nuffield Foundation's Scheme for the Advancement of Extraction Metallurgy. Under the terms of this scholarship he is at present in the United States of America, where, through the courtesy of the American Institute of Mining and Metallurgical Engineers, he is making an

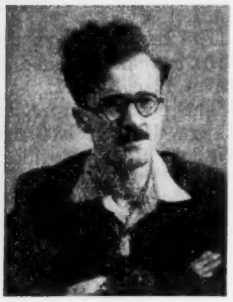


G. V. Slottman

J. Nortcliffe

K. J. Irvine

J. G. Wistreich



M. H. Roberts

H. T. Shirley

R. Weil

exhaustive study of the latest developments in the iron and steel industry, based on the Great Lakes ore-fields. Mr. Irvine has also visited the principal universities and technical institutes in the United States in order to study their facilities and teaching methods.

J. G. Wistreich, M.Sc.(Eng.)—Officer in charge of wire-drawing research, British Iron and Steel Research Association. Mr. Wistreich was born in Warsaw in 1920, receiving his early education in Poland; in 1944 he graduated with a First Class Honours Degree in Mechanical Engineering at University College, London. For two years he carried out research in fluid-flow problems at the City and Guilds of London Institute, receiving the Diploma of the Imperial College of Science in 1946, and the degree of M.Sc.(Eng.) in 1947 for a thesis on "The Adiabatic Flow of Compressible Fluids in Pipes."

Mr. Wistreich took up his present appointment with the British Iron and Steel Research Association in August 1946.

W. L. Kerlie, B.Sc.—Technical Development Metallurgist at Messrs. Stewarts and Lloyds, Ltd., Corby. For further details see the October issue of the *Journal* (p. 283).

M. H. Roberts, B.Sc.—A member of the staff of the Physics Department, Brown-Firth Research Laboratories, Sheffield. Mr. Roberts was born in July 1922, and was educated at King Edward VII School, Sheffield, and at Sheffield University, where he obtained the degree of B.Sc. (Hons.) in physics.

In the following year he joined the staff of the Brown-Firth Research Laboratories, working mainly on the application of electronic technique to problems of testing, strain measurement, and temperature control, both in works processes and in research.

H. T. Shirley, B.Sc., A.R.C.S.—Chief Chemist, Brown-Firth Research Laboratories, Sheffield. Mr. Shirley was educated at Tiffin School, Kingston-on-Thames, and at the Imperial College of Science and Technology, London, where he graduated in 1926. In that year he entered the Brown-Firth Research Laboratories as a physical chemist, specializing in matters relating to corrosion.

Since 1939 Mr. Shirley has carried out an intensive study of the application of spectrography to steel analysis and published a paper on this subject with E. Elliott in the *Journal of the Iron and Steel Institute* in 1943.

Mr. Shirley became a Member of the Iron and Steel Institute in 1934, of the Joint Research Committee on Corrosion (now the Corrosion Committee of the British Iron and Steel Research Association) in 1943, and Vice-Chairman of the British Iron and Steel Research Association Spectrographic Analysis Sub-Committee in 1946. As co-author with the late Dr. W. H. Hatfield, F.R.S., he wrote a number of papers for the Joint Research Committee on Corrosion.

A. Preece, B.Sc., M.Sc., F.I.M.—Lecturer and Reader in Metallurgy at Leeds University. Mr. Preece was educated at Port Talbot County School and at Swansea University. His previous positions have included those of Assistant Metallurgist at the Pressed Steel Company of Great Britain, Research Assistant to Principal C. A. Edwards, F.R.S., at Swansea University, and Research Officer at the South Wales Siemens Steel Research Association. Mr. Preece is President of the Leeds Metallurgical Society and a member of a number of national committees.

R. Weil, M.Sc.—Lecturer in Physics at South-West Essex Technical College. Born in Prague, Mr. Weil came to this country after the German occupation in 1939, and studied physics at the University College, Nottingham, obtaining a B.Sc.(Hons.) degree in 1944. Three years later he was awarded the degree of M.Sc. for a thesis on his work carried out for the British Iron and Steel Research Association.

Mr. Weil has been successively a wireless mechanic, a laboratory assistant in a sugar factory, assistant science master at the Girls' High School, Newark, and research assistant to Dr. H. Lowery, under contract with the British Iron and Steel Research Association. He took up his present appointment in September.

IRON AND STEEL ENGINEERS GROUP

Membership

A number of engineers have recently applied for election as members of the Institute without asking to be enrolled in the Iron and Steel Engineers Group.

The Institute sends to each candidate for membership of the Institute a notice about the Engineers Group and a reply form, by completing and returning which, the candidate becomes a member of the Group. It is possible that a number of candidates for membership have not received these notices. Any Institute Member, or candidate for membership, who

wishes to join the Iron and Steel Engineers Group and has not completed a reply form is asked to apply to the Secretary. Members of the Institute pay no extra fee to join the Engineers Group. Details of the objects and functions of the Group are given on pages 86 to 88 of the January issue and on pages 566 and 567 of the August issue of the *Journal*.

Future Meetings

London

The **Fifth Meeting** of the Iron and Steel Engineers Group will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 26th November, 1947.

At the morning session, Mr. W. W. Franklin and Mr. P. F. Grove will present for discussion a paper on "*The Mechanical and Electrical Features of the Principal Hot-Rolling-Mill Auxiliaries.*"

After a Buffet Luncheon, to be held in the Library, the afternoon session will be devoted to the presentation and discussion of a paper on "*Modern Small Rolling Mills*" by Mr. G. A. Phipps. The two papers for this meeting were published in the October issue of the *Journal*.

The **Sixth Meeting** of the Group will be held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 18th February, 1948. The morning session will be devoted to the presentation and discussion of a paper on "*The Engineering Aspects of the Distribution and Utilization of Gaseous Fuels in Iron and Steel Works*" by J. B. R. Brooke (John Lysaght, Ltd.). During the afternoon session a paper on "*Soaking Pits*" by the Society of Furnace Builders will be presented and discussed.

Provinces

Five joint meetings have, so far, been arranged between the Iron and Steel Engineers Group and the Local Societies affiliated to the Institute. They are as follows:

1947

18th Dec.—Joint meeting at Scunthorpe with the Lincolnshire Iron and Steel Institute. Mr. T. H. Stayman (Head, Wrightson & Co., Ltd.) will present his paper, "*Some Notes on Recent American Blast-Furnaces*," published on pages 136 to 140 of the January issue of the *Journal*.

1948

15th Jan.—Joint meeting at Dudley with the Staffordshire Iron and Steel Institute. Mr. G. A. Phipps (Guest Keen and Nettlefolds, Ltd.) will present his paper on "*Modern Small Rolling Mills*," published on pages 247 to 261 of the October issue of the *Journal*.

19th Jan.—Joint meeting in Sheffield with the Sheffield Society of Engineers and Metallurgists. Mr. W. W. Franklin (Davy and United Engineering Co., Ltd.) and Mr. P. F. Grove (John Miles and Partners (London), Ltd.) will present their paper on "*The Mechanical and Electrical Features of Primary Hot-Rolling-Mill Auxiliaries*," published on pages 262 to 278 of the October issue of the *Journal*.

21st Feb.—Joint meeting in Swansea with Swansea and District Metallurgical Society. Mr. W. F. Cartwright (Steel Company of Wales, Ltd.) will read a paper on "*The Engineering Aspects of a Modern Steelplant.*"

4th March.—Joint meeting in Leeds with Leeds Metallurgical Society. Dr. A. T. Bowden (Messrs. C. A. Parsons & Co., Ltd.) will present the paper on "*Gas Turbine Applications in Iron and Steel Works*," published on pages 98 to 118 of the May issue of the *Journal*.

It is hoped to arrange joint meetings during the early part of 1948 with:

The West of Scotland Iron and Steel Institute,
The Cleveland Institute of Engineers,
The Newport and District Metallurgical Society.

Details will be announced later.

Papers

The Engineering Committee is anxious to receive from Members of the Group, or from other engineers within or connected with the iron and steel industry, papers on iron and steel works engineering subjects, with a view to their publication in the Iron and Steel Works Engineering Section of the *Journal*.

Arrangements are in hand for the publication of technical descriptions of the new plant being erected in the industry. One such description appears in this issue. Others will be appearing in the Engineering Section of the *Journal* from time to time.

As stated on page 567 of the August issue of the *Journal*, the Engineering Committee will be pleased to receive papers with a view to their consideration for the award of the Ablett Prize, and will welcome short notes or articles concerning practical ideas for the improvement of steelworks equipment and processes.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Blast-Furnace Conference

The 14th Blast-Furnace Conference was held at Ashorne Hill on 1st October, 1947, under the chairmanship of Mr. G. H. Johnson. The subject for discussion was the formation of 'scaffolds.'

Mr. G. Elliot's general introduction was read by Mr. C. Hulme, manager of North Ironworks at the Appleby Frodingham Steel Co., and was followed by talks by Dr. G. R. Rigby of the British Refractories Research Association on "*Theories Regarding the Formation of Scaffolds*," and by Dr. J. H. Chesters of the United Steel Companies, Ltd., on "*An Examination of Scaffolds and Scaffold-Forming Materials.*"

In spite of considerable variations in the detailed structure and mode of formation of scaffolds, which

were described, it was pointed out that the most probable general factor in scaffold formation is the alkaline attack on the refractories.

Steelmaking Conference

The 29th Steelmaking Conference was held at Ashorne Hill on 8th and 9th October, 1947, under the chairmanship of Mr. J. Mitchell of Messrs. Stewarts and Lloyds, Ltd. The general subject for discussion was the relative merits of various methods of steelmaking considered from the technical and economic points of view.

Mr. A. Jackson gave a talk on the basic open-hearth process, followed by Mr. W. Ash on the acid open-hearth, Mr. J. Glen and Mr. F. B. Cawley on the basic and acid bessemer processes respectively, Mr. J. Mowat on the electric process and Mr. S. Spray* on a combined cupola melting–converter process developed during the war.

After a summing up by Dr. T. P. Colclough general discussion followed. Whilst the general consensus of opinion was that each process has its own particular field, the view was expressed that both the basic bessemer and electric processes could be used for the manufacture of a much wider variety of steels than at present. It was understood that BISRA is giving special attention to the possibilities of extending the field of these processes and of the use of the relatively unorthodox process described by Mr. Spray.

Works Chemists' Conference

The First Works Chemists' Conference under the auspices of the Association was held at Ashorne Hill, Leamington Spa, on 15th and 16th October, 1947. Proceedings were divided into three sessions.

Mr. E. J. Vaughan, acting chairman, expressed his regret that Dr. E. Gregory was unable to take the chair owing to indisposition, and opened the first session, which was devoted to submission and discussion of standard methods of analysis, prepared by the co-operative work of chemists in the Association, and forwarded by BISRA to the British Standards Institution for publication.

During the second session the chairman of various sub-committees set up by BISRA outlined the past and future work of their committees in preparing such standard methods as those already presented.

Mr. G. E. Speight took the chair for the third session and introduced Dr. F. D. Richardson, Head of BISRA Chemistry Department, whose explanation of the theory of reaction in steelmaking furnaces promoted lively and valuable discussion on practical applications of his results.

Physics Laboratories at Battersea

The Physics Laboratories of the British Iron and Steel Research Association were officially opened at 140, Battersea Park Road, London, S.W.11, on Wednesday, 22nd October, 1947.

To the many distinguished guests assembled at the luncheon which marked the opening ceremony, the Rt. Hon. Lord Rayleigh, F.R.S., delivered the inaugural address, in which he spoke of the early developments in the making of steel and of the great importance of pyrometry to the scientific control of the steelmaking process. In setting up the new Physics Laboratories the Association had made a great contribution to the progress of science and technology.

Following Lord Rayleigh, on behalf of the Department of Scientific and Industrial Research, Sir Edward Appleton, F.R.S., welcomed the opportunity of offering the Department's congratulations on this extension of the Association's activities. Mr. D. A. Oliver, Research Director of the B.S.A. Group, then spoke on behalf of the Council of the Association and referred to the close co-operation which existed between the laboratories of the Association and industry and also the Universities.

The opening ceremony was followed by an inspection of the premises and of the equipment already assembled. During the structural alterations which have been in progress for a year quite a large amount of investigations have been conducted and the visitors were able to see some of the results already obtained.

The Physics Department is divided into four sections corresponding to the four main lines of connection between physics and steelmaking, on which the arrangement of the laboratories is also based. The sections are: (i) General Physics, (ii) Instruments, (iii) Heat and Thermodynamics, (iv) Aerodynamics, and (v) Mathematics. Each section is allotted one main laboratory and two or three small offices, while in addition the Heat Section has a high-temperature-furnace room for radiation and pyrometric experiments, and the General Physics Section has an X-ray laboratory and dark-rooms.

In addition to the Physics Department, the Association has accommodated at Battersea a laboratory of the Chemistry Department and temporary facilities to the Steelmaking Division for carrying out work connected with instrument and process chemistry.

The establishment of these new laboratories will undoubtedly provide a further important avenue by which the Association can fulfil its functions of keeping in touch with advances in science with a view to possible application in the iron and steel industry, and of carrying out fundamental research in a way not possible in the existing industrial laboratories.

Process Measuring and Control Instruments in the Iron and Steel Industry

In conformity with the British Iron and Steel Federation's plan for the industry, the Association is assisting in encouraging the wider application of modern measuring and control instruments by providing an Instrument Advisory Service in the Instruments Section of the Physics Department at Battersea. This Service is open to members of the industry for information on developments in instrumentation techniques, merits and availability of particular instruments, and general problems of plant instrumentation. Advantage has already been taken of this Service by some member firms, and assistance provided in procuring suitable instruments.

Considerable attention is being given to the present

* This process is fundamentally the same as that described by P. C. Fassotte in the *Journal of the Iron and Steel Institute*, 1944, No. II, p. 339.

serious shortage of instruments, and close liaison has been established with individual instrument manufacturers and their Associations. One outcome of this is that, with help from the British Iron and Steel Federation, an estimate has been made of the probable requirements of the industry for instruments over the next five years, and the information passed to the instrument manufacturers' Associations. Taking into account the requirements of other user industries, it is indicated that the present production capacity of the British instrument industry is considerably below that required, and means of improving the situation are being considered in conjunction with the Ministry of Supply and the instrument industry. An Instrument Industry Committee has recently been set up within the British Standards Institution, which it is hoped will eventually contribute towards improvement in the supply situation.

Preliminary consideration is also being given to the problem of training instrument mechanics in sufficient numbers to provide efficient maintenance.

AFFILIATED LOCAL SOCIETIES

Cleveland Institution of Engineers

The list of Officers for the session 1947–1948 is as follows :

President

C. MOODY

Hon. General Secretary and Treasurer	Hon. Technical Secretary
F. G. E. WEBSTER	L. STEPHENSON

Members of Council

N. BLANEY	N. C. LAKE
E. F. BROWN	F. SHEPHERD
H. FEATONBY	W. W. STEVENSON
E. T. JUDGE	G. B. THOMAS
F. KENNEDY	T. W. THURSFIELD

H. H. UTLEY

The lecture programme for the new session is given below :

1947

1st Dec.—"*Combination Rolling Mills*," by W. Udall.

1948

5th Jan.—"*Desiliconization*," by E. F. Brown (Skinningrove Iron Co., Ltd.)

2nd Feb.—"*Some Aspects of Modern Blast-Furnace Operation*," by R. P. Towndrow (Colvilles, Ltd.).

1st Mar.—"*Metallurgical Load as a Factor in Basic Open-Hearth Furnaces*," by A. J. Kesterton (Dorman, Long & Co., Ltd.).

5th April—Discussion Meeting on "*Oil Firing of Open-Hearth Furnaces*," by G. B. Thomas (Cargo Fleet Iron Co. Ltd.) and F. Kennedy (Dorman, Long & Co., Ltd.)

Meetings are held at the Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, and will commence at 6.30 P.M.

DIARY

26th November

MANCHESTER METALLURGICAL SOCIETY—"*Some Metallurgical Problems in the Field of Atomic Energy*," by E. W. Colbeck (Joint Meeting with Iron and Steel Institute and Institute of Metals)—Engineers' Club, Albert Square, Manchester, 6.30 P.M.

26th November

IRON AND STEEL ENGINEERS GROUP—Fifth Meeting on "*Rolling-Mill Auxiliaries*"—4, Grosvenor Gardens, S.W.1.

27th November

MIDLAND METALLURGICAL SOCIETIES—"*Protective Coatings*," by W. E. Ballard—James Watt Institute, Great Charles Street, Birmingham, 6.30 P.M.

1st December

CLEVELAND INSTITUTION OF ENGINEERS—Lecture on "*Combination Rolling Mills*," by W. Udall—Cleveland Scientific and Technical Institute, Corporation Road, Middlesborough, 6.30 P.M.

3rd December

LEEDS METALLURGICAL SOCIETY—"*Aluminium Alloys*," by H. G. Warrington—Chemistry Department, Leeds University, 7.0 P.M.

4th December

LEEDS METALLURGICAL SOCIETY—Buffet Dance—Astoria Ballroom, Leeds, 8 P.M.–2.0 A.M.

10th December

MANCHESTER METALLURGICAL SOCIETY—"*Controlled Atmospheres for Heat Treatment of Metals*," by Ivor Jenkins—Engineers' Club, Albert Square, Manchester, 6.30 P.M.

11th December

STAFFORDSHIRE IRON AND STEEL INSTITUTE—Display of Industrial Films—Dudley and Staffordshire Technical College, Dudley, 7.0 P.M.

13th December

NEWPORT AND DISTRICT METALLURGICAL SOCIETY—"*Forged Steel Rolls*," by A. H. Waine—Newport Technical College, 6.30 P.M.

13th December

SWANSEA AND DISTRICT METALLURGICAL SOCIETY—"*Oil-Firing of Metallurgical Furnaces*," introduced by R. W. Evans, A. M. Gabe and J. S. Lewis—Royal Institution of South Wales, Swansea, 6.30 P.M.

16th December

SHEFFIELD METALLURGICAL ASSOCIATION—Discussion on "*Ingot Surface Defects*"—198, West Street, Sheffield, 7.0 P.M.

16th December

LINCOLNSHIRE IRON AND STEEL INSTITUTE—"*Some Notes on Recent American Blast-Furnaces*," by T. H. Stayman (Joint Meeting with the Iron and Steel Engineers Group, the Iron and Steel Institute)—Technical School, Cole Street, Scunthorpe, 7.30 P.M.

TRANSLATION SERVICE

Since the announcement made in the October issue of the *Journal* (*see* page 288), further translations have been put in hand and the following are now available or in the course of preparation

TRANSLATIONS AVAILABLE.

No. 322 (French). R. GIRSCHIG : "A New Micro-Hardness Tester. The L.C. Microsclerometer." (*Revue de Métallurgie*, 1946, vol. 43, Mar.–Apr., pp. 95-112).

No. 323 (German). K. RUMMEL : "The Gas Balance in Iron and Steel Works." (*Stahl und Eisen*, 1947, vol. 66–67, Jan. 2, pp. 19–23).

No. 324 (German). P. BARDENHEUER and W. GELLER : "The Basic Principles of the Desulphurization of Pig Iron and Steel." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1934, vol. 16, No. 7, pp. 77–91).

No. 325 (Russian). M. A. GLINKOV and V. C. KOCKO : "On the Question of Heat Transfer in a Molten Bath by Gas Bubbles." (*Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques*, 1946, No. 10, pp. 1463–1472).

TRANSLATIONS IN COURSE OF PREPARATION

(German). H. BABLICK and F. GÖTZL : "Alloy Additions to Hot-Galvanizing Baths." (*Korrosion und Metallschutz*, 1941, vol. 17, Apr. pp. 128–130).

(German). H. BALICK, F. GÖTZL and R. KUKACZKA : "The Structure of Hot-Galvanized Coatings." (*Korrosion und Metallschutz*, 1945, vol. 21, p. 1).

(German). W. BADING : "The Development of Basic Converter Practice." (*Stahl und Eisen*, 1947, vol. 66–67, Apr. 24, pp. 137–149 ; May 22, pp. 180–186 ; June 19, pp. 212–223).

(Swedish). E. BERNHULT : "The Yield Point in Bending and the Stress Distribution in Bars and Tubes in Plastic Bending." (*Jernkontorets Annaler*, 1943, vol. 127, No. 16 pp. 491–533).

(Swedish). E. BERNHULT: "The Calculation of Roll Pressure and its Effect in the Cold-Straightening of Bars and Tubes." (*Jernkontorets Annaler*, 1944, vol. 128, No. 4, pp. 137–160).

(German). G. BULLE : "The Production of Pig Iron with Low-Iron Burdens." (*Stahl und Eisen*, 1947, vol. 66–67, Mar. 27, pp. 69–78).

(German). W. EILENDER and W. ROESER : "Metallurgical Investigations on the Working of the Basic-Bessemer Process with Oxygen-Enriched Blast" (*Stahl und Eisen*, 1939, vol. 59, Sept. 21, pp. 1057–1067).

(German). E. SIEBEL : "Present Knowledge of the Mechanics of Wire Drawing." (*Stahl und Eisen*, 1947, vol. 66–67, May 22, pp. 171–180).

(Russian). F. F. VITMAN, N. N. DAVIDENKOV, and N. A. ZLATIN : "Cold-Brittleness of Steel in Torsion." (*Journal of Experimental and Theoretical Physics, U.S.S.R.*, 1940, vol. 10, Nos. 9–10, pp. 1137–1145).

(German). A. GELEJI : "The Theoretical Problems Involved in the Design of Rolling-Mill Stands." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 224–242).

(German). A. GELEJI : "Calculating the Forces Arising and the Power Requirements in the Mannesmann Tube-Rolling Process." (*Royal Hungarian Palatine-Joseph University, Publications of the Department of Mining and Metallurgy*, 1941, vol. 13, pp. 208–223).

(German). G. F. HÜTTIG : "The Theoretical Bases of Sintering Processes in Powders." (*Metallwirtschaft*, 1944, vol. 23, Oct. 20, pp. 367–372).

(German). K. KINTZINGER : "Operating Measures in the Sintering of Iron Ores." (*Stahl und Eisen*, 1943, vol. 63, June 10, pp. 453–456).

(German). J. KLÄRDING : "The Sintering of Iron Ore with Added Lime." (*Archiv für das Eisenhüttenwesen*, 1939, vol. 12, May, pp. 525–528).

(French). P. LAURENT : "Contribution to the Theory of the Plasticity of Metals and Alloys." (*Revue de Métallurgie*, 1945, vol. 42, Mar., pp. 72–92 ; Apr., pp. 125–132, May, pp. 156–167 ; June, pp. 194–203 ; July, pp. 230–239).

(German). W. LENNINGS : "Smelting of Basic-Bessemer Pig Iron from Low-Grade German Ores in the Blast-Furnace with Acid Slag Practice." (*Stahl und Eisen*, 1938, vol. 58, Jan. 13, pp. 25–35 ; Jan. 20, pp. 52–58).

(Swedish). G. MALMBERG : "The Effect of Specimen Shape on the Elongation in Tensile Testing." (*Jernkontorets Annaler*, 1944, vol. 128, No. 6, pp. 197–245).

(Swedish). S. MÖRTSELL : "Rationalization in Swedish Iron-Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 130, No. 9, pp. 369–460).

(German). W. OELSEN and H. WIEMER : "Immiscibility Phenomena in Ferrous-Oxide/Sodium-Phosphate Slags." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 13, pp. 167–210).

CHARGES FOR COPIES OF TRANSLATIONS.—For the above translations a charge will be made of 10*s.* for the first copy and 5*s.* each for each additional copy of the same translation. Requests should be accompanied by a remittance. The above translations are not available on loan from the Joint Library.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST.—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the series.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

New Coal Discoveries in Tanganyika. G. M. Stockley. (Mining Magazine, 1947, vol. 76, June, pp. 329–338). An account is given of the geology of the Njurga and Muhukulu coalfields in Tanganyika. Proximate analyses of coal samples from both fields are tabulated.—R. E.

The Geology of the Namwele-Mkomolo Coalfield, Ufipa District : With Notes on Underground Exploration Carried Out by the Tanganyika Government. R. B. McConnell. (Bulletin of the Imperial Institute, 1946, vol. 44, Oct.–Dec., pp. 330–354). This consists of four appendices to the original paper (*see* Journ. I. and S.I., 1947, vol. 155, Feb., p. 297), recording factual data and conclusions arrived at from tests on coal samples from this coalfield. The coal is a non-caking bituminous coal with high volatile, ash, and sulphur contents, the ash having a comparatively low fusion temperature.—R. E.

The Metal Resources of India, China, and the East Indies. J. A. Dunn. (Australian Institute of Metals : Australasian Engineer, 1947, June 7, pp. 62–66). A summary is made of the resources and present production of each of the metals of metallurgical importance in India, China, and the East Indies.—C. O.

Refractory Raw Materials in Southern India. B. Rama Rao. (Journal of the Geological, Mining and Metallurgical Society of India, 1946, vol. 18, Dec., pp. 85–95). A survey is made of the abundant sources of refractory raw materials in Southern India, and the extent of their exploitation is indicated.—C. O.

The Iron Ores of Germany. A. E. Lance. (Journal of the Iron and Steel Institute, 1947, vol. 156, Aug., pp. 449–476). Descriptions of the iron-ore deposits in Germany, the different types of ore mined, and a general outline of mining methods used are given, accompanied by schedules of the analyses and classification of the ores, the reserves, and the monthly output for each mine.

Mineral Resources of Turkey and Their Exploitation by the Eti Bank. M. Verchere. (Revue de l'Industrie Minérale, Mémoires, 1941, Sept.-Oct., pp. 139–146). The Eti Bank was formed in 1935 to exploit the mineral resources of the Turkish Republic and it controls seven mines. Other mines not controlled by the Eti Bank are mentioned and statistics given for the years 1938 and 1939.—R. F. F.

Future of the Lake Superior Iron Ranges in Present Shipping Grades. L. P. Barrett. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, 1946, Apr., pp. 70–76). The extent of the remaining iron-ore reserves of the Lake Superior region is discussed.—R. A. R.

Quality and Characteristics of Future Iron-Ore Supply. W. L. Maxson. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, 1946, Apr., pp. 81–84). Problems confronting the producers and consumers of the iron ores of the Lake Superior region are discussed. The period of very many grades of high quality, blended to exact specifications, is ending and users will have to adjust themselves to fewer grades and to a large increase in the proportion of agglomerated raw materials.—R. A. R.

Metals, Minerals and Research. C. Williams. (Transactions of the Canadian Institute of Mining and Metallurgy 1947, vol. 50, pp. 131–137). The production of metals, the rate of depletion of the mineral resources of Canada and the United States, and the part played by research in making good deficiencies and maintaining a high standard of living are discussed.—R. A. R.

The World Situation on Coating Materials—Lead, Zinc, and Tin. C. A. Ilgenfritz. (American Iron and Steel Institute, May, 1947, Advance Copy). A short account is given of the principle sources of ores of lead, zinc, and tin, of the present and pre-war production of these metals, and of the outlook for future supplies in the United States.—C. O.

The Mineral Resources of Poland's Prospective Suppliers. S. Holewinski. (Hutnik, 1945, No. 5, p. 173 and 1946, No. 1, pp. 1–9). [In Polish]. The world resources of minerals, chiefly iron ores and alloying elements, are discussed, and a conclusion is drawn about the possibilities of future supplies to Poland.—W. J. W.

What to Do about Our Iron Ore Reserves. C. F. Park, jun. (Mining and Metallurgy, 1947, vol. 28, Apr., pp. 192–196). A general survey of the iron-ore resources of the world is made; it shows that the average grade of the ore used to-day is lower than it was 20 years ago. The author considers that the United States should not increase the imports of foreign ores, but should intensively search for new indigenous high-grade deposits. —R. A. R.

The Occurrence and Reserves of Raw Materials Containing Fluorine, especially Fluorspar, in Industry. E. Sauerbrey. (Technik, 1947, vol. 2, July, pp. 315–318). A survey is presented of the world's resources of fluorine-bearing minerals, their production, preparation, and use.—R. A. R.

ORES—MINING AND TREATMENT

Churn-Drill Performance. J. R. Thoenen and E. J. Lintner. (United States Bureau of Mines, 1947, Report of Investigations No. 4058). The results of drilling tests in limestone and sandstone quarries, using churn drills, are presented and discussed.—R. A. R.

Note on Feeding and Screening Apparatus in Primary Crushing Plants with Special Reference to the Crushing of Lorraine Iron Ores. E. C. Blanc. (Revue de l'Industrie Minérale, Mémoires, 1944, Dec., pp. 491–496). The different types of crushing plants are discussed and a description of certain of them is given.—R. F. F.

Underground Crushing in Swedish Mines. A. Kjelgaard. (Teknisk Tidskrift, 1947, vol. 77, Aug. 9, pp. 577–581). [In Swedish]. Several types of iron-ore crushers are described and the advantages of preliminary crushing and screening underground are discussed.—R. A. R.

Recent Investigations of the Crushing Properties of Ore and Rock. S. Mörtsell. (Teknisk Tidskrift, 1947, vol. 77, Aug. 9, pp. 583–585). [In Swedish]. The results, of crushing tests on hard and soft Swedish iron ores are presented and discussed. The effect of changes in the gap width on the throughput and current consumption were determined.—R. A. R.

Crushing of Ores and Preparation of Blast-Furnace Charges. R. L. Dardenne. (Revue de l'Industrie Minérale, Mémoires, 1943, Feb., pp. 85–115; Mar., pp. 157–176, July, p. 434). This is a general review with a bibliography.—R. F. F.

Standard Grindability Tests Tabulated. F. C. Bond. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2180 : Mining Technology, 1947, vol. 11, July). Four tables are presented containing the results of several hundred tests of the standard ball-mill and rod-mill grindabilities and the impact-crushing strength of numerous minerals; a comparison is made between the standard and the open-circuit grindability tests.—C. O.

Technology Will Solve Our Iron-Ore Problems. C. Zappfe. (Engineering and Mining Journal, 1947, vol. 148, July, pp. 88–90). The author believes, that, in view of the enormous tonnages of low-grade ore in the Lake Superior region, amenable to concentration, the supplies to the American industry will be assured for many generations if improved methods of concentration are used.—R. E.

Removal of Sulphur from High-Sulphur Iron Ore by Sintering. H. K. Work and F. M. Hamilton. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, 1946, Apr., pp. 85–92). Laboratory and full-scale tests of the removal of sulphur from ore by sintering are described. A high degree of desulphurization was obtained, the sinter being quite satisfactory for the blast-furnace. The amount of large lumps in the sinter mix must not exceed a certain proportion.—R. A. R.

Results Obtained at the Boël Works, by the Preparation of Charges. J. Latourte. (Revue de l'Industrie Minérale, Mémoires, 1943, Mar., pp. 177–182). The results obtained at the Boël works with the recently installed ore-crushing, screening, sintering, and agglomerating plant are described.—R. F. F.

FUEL—PREPARATION, PROPERTIES, AND USES

Theory of Burning Velocity. I.—Temperature and Free Radical Concentrations Near the Flame Front, Relative Importance of Heat Conduction and Diffusion. C. Tanford. (Journal of Chemical Physics, 1947, vol. 15, July, pp. 433–439). Differential equations are obtained for the heat transfer and material transport near flame fronts, and these equations are solved for the particular cases of a mixture containing oxygen and moist carbon monoxide and a mixture containing oxygen, nitrogen, and hydrogen. It is shown that the temperature falls rapidly with distance from the flame front, and the local thermal-equilibrium concentration falls even more rapidly being a negative exponential of the temperature. The local non-equilibrium concentration of hydrogen atoms, which is caused by diffusion, falls only slowly with distance. Hence it is concluded that diffusion plays a more important part than heat transfer. —C. O.

Heat Transfer between a Fluid and a Porous Solid Generating Heat. S. R. Brinkley, jun. (Journal of Applied Physics, 1947, vol. 18, June, pp. 582–585). Anzelius' theory of the transfer of heat between a fluid and a porous solid through which it is flowing at constant velocity is extended to include solids generating heat. On the assumption that the function of the heat source is a linear function of the temperature of the solid, with coefficients independent of position and time, expressions are derived for the temperatures of the fluid and the solid in terms of position and time.—C. O.

Kinetics of Chemical Reactions in Flames. Ya. B. Zeldovich and N. N. Semenov. (Iron and Steel Institute, 1947, Translation Series No. 318). This is an English translation of a paper which was published in Journal of Experimental Physics, U.S.S.R., 1940, vol. 10, No. 9–10, pp. 1116–1136.—R. A. R.

A Steelworks Economises Fuel. (Power and Works Engineering, 1947, vol. 42, Aug., pp. 229–235). A description is given of a new boiler-plant equipment installed at the Workington plant of The United Steel Companies, Ltd. The installation includes two high-pressure boilers, each rated for 80,000 lb/hr. evaporation

and equipped for firing blast-furnace and coke-oven gas in any desired proportion. There is no provision for coal firing, the alternative fuel being creosote-pitch.—J. R.

Coal Ash: Chemical Composition as a Guide to Behaviour in Furnaces. G. A. Cave. (The British Coal Utilisation Research Association Monthly Review, 1947, vol. 11, May, pp. 141–148). The work of various investigators on the determination of softening temperature, relation between softening temperature and chemical composition, determination of slag viscosity and its relation to chemical composition and on clinker formation is reviewed. It is concluded that sufficient knowledge is now available for the suitability of a coal for slag-tap firing to be predicted from the slag analysis and a knowledge of furnace conditions.—M. A. V.

Theoretical Interpretation of Washability Curves. W. Budryk. (Annales de l'Académie Polonaise des Sciences Techniques, 1939–1945, vol. 7, pp. 99–112). The practical application of washability curves for coal is discussed.—R. A. R.

The Rational Preparation of Coal. R. Lessing. (Institute of Fuel: Fuel, 1947, vol. 26, May-June, pp. 57–73). This paper appeared originally in Journal of the Institute of Fuel, 1943, vol. 17, Oct., pp. 15–24. (*see* Journ. I. and S.I., 1941, No. I, p. 41A).

New Dry Cleaning Plants at Holmside. C. W. H. Holmes. (North of England Institute of Mining and Mechanical Engineers: Colliery Guardian, 1947, vol. 175, July 25, pp. 105–107; Aug. 1, pp. 139–152). The disadvantages of certain coal-cleaning plant at the Holmside and South Moor collieries in Durham are outlined and details of a new dry-cleaning plant for cleaning 2-in. to 0 smalls at the rate of 75 tons/hr. are given.—R. A. R.

Coal Cleaning Practice at Albion Colliery. (Iron and Coal Trades Review, 1947, vol. 155, Aug. 22, pp. 347–351). A description is given of the coal-production plant at the Albion Colliery near Pontypridd. The equipment, which consists of a Chance gravity washer, a rhéolaveur trough washer, and a Birtley aspirator, is designed to handle 200 tons/hr. of up to 8-in. size and has proved to be economical, efficient, and extremely flexible in operation.—J. R.

Proceedings of the Blast Furnace and Raw Materials Conference. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, Apr., 1946). This Conference which was held at Chicago on April 25 and 26, 1946, was divided into three sessions dealing respectively with coal and coke, refractories, and ore. Abstracts of two of the seven papers which were presented are given below; abstracts of the other five papers will be found in the sections on refractories and ores.—R. A. R.

New Developments in Coal-Washing Practice. W. L. McMorris, jun. (*Ibid.*, pp. 2–10). After very briefly reviewing modern methods of cleaning coal, the author describes the blending and washing plant under construction at the Robena mine, which is planned to clean 25,000 tons of coal per day.—R. A. R.

A Report on Inland's Research Program for Selection of Suitable Low-Volatile Coking Coal to be Used in Manufacture of Metallurgical Coke. E. J. Gardner. (*Ibid.*, pp. 16–31).

The Characteristics of Pulverized Coal. (Department of Scientific and Industrial Research, 1947, Fuel Research Technical Paper No. 49). An investigation was carried out to determine the influence on the type of coal and the type of mill on the physical properties of pulverized coal. Five different coals ranging from a meta-ignitous to an ortho-semi-bituminous coal were examined after grinding in six different types of mill (ball mill, tube mill, ring-ball mill, emery mill, hammer mill, and peg mill).—M. A. V.

Non-Mechanical Methods of Size-Reduction. E. Murphy, F. F. Ross, and G. C. H. Sharpe. (The British Coal Utilisation Research Association Bulletin, 1947, vol. 11, July, pp. 221–233). There are three processes by which solid particles may be reduced in size without the use of mechanical mills—"impact," *i.e.*, the impact of the particles on a comparatively large solid surface; "attrition," *i.e.*, the rubbing of particles on each other, or collisions between them; and "explosion," *i.e.*, the disruption of particles from within by a sudden release of external pressure. The article describes types of mill in which these processes, are used for the comminution of a number of substances, and especially for the pulverization of fuel.—J. P. S.

Theory of Screening Efficiency. F. Michelin. (Revue de l'Industrie Minérale, Mémoires, 1945, Sept., pp. 317–339). The maximum and minimum efficiency of screening with a known mesh, the necessary increase in size of the mesh for optimum efficiency, and the minimum and maximum particle-size curve for marginal-size particles can be calculated by the theory which the author advances.—R. F. F.

Practical Experiences in the Coking of Dangerous Low-Ash Coals. D. T. Barritt. (Journal of the Institute of Fuel, 1947, vol. 20, Aug., pp. 161–179). The considerations which influenced the design of a new coking plant to produce a low-ash, high-density coke from compressed charges of Kilsyth (Scotland) coking coal are outlined. An account is given of experiences and difficulties encountered at this plant with dangerously swelling coals, and of tests made to determine the nature of this swelling. A number of recommendations are made concerning the design of future compressed-charge plants.—C. O.

Carbonization of Coal Sprayed with Oil. P. C. Mayfield. (American Iron and Steel Institute, May, 1947, Advance Copy). Experience with the use of oil-treated coal in by-product coking is described. The quantity of oil added to the coal mixture was gradually increased from 1 to 2½ gal./ton, without causing any difficulty in conveying or charging, nor was there any apparent change in the structure or appearance of the coke. The addition of half a pint of a light absorbent oil was found to increase the bulk density of the coal charge by as much as 6–8%.—C. O.

Fire Prevention and Safety in By-Product and Benzol Plants. R. W. Schirmer. (Iron and Steel Engineer, 1947, vol. 24, July, pp. 76–80). Precautions against fire hazards in by-product and benzol plants are suggested.

Experiments to Improve Coke Strength. C. W. Stahl. (American Iron and Steel Institute, May, 1947, Advance Copy). The coal-preparation and coke-oven equipment and the methods used in experiments on the strength of coke by the Bethlehem Steel Company are briefly described. The A.S.T.M. tumbler stability test was used to measure the strengths of cokes produced in 200 tests with various types and sizes of pulverized coals. It was confirmed that coal quality was the most important variable affecting strength and that coke strength increased with fineness of pulverization. Preheating the coal to 470° F. appears to reduce the coking time but not to effect the coke strength.—C. O.

Uniformity—Its Application to the Quality of Metallurgical Cokes. C. G. Thibaut. (Revue de l'Industrie Minérale, Mémoires, 1945, Sept, pp. 341–347) The methods used for checking the uniformity of the properties of metallurgical cokes are described, and a short bibliography is appended.—R. F. F.

The Physical Constitution of Metallurgical Cokes. C. G. Thibaut. (Revue Technique Luxembourgeoise, 1947, vol. 39, July-Sept., pp. 144–166). This is a review of developments in the manufacture and of the quality of metallurgical cokes. Methods of testing coke are described. A bibliography is appended.—R.F.F.

Loss of Combustibles in Furnace and Producer Ash and Clinker. (Gas Review, 1947, vol. 1, June, pp. 602–605). The properties of ash and clinker and a test for determining the fusion point of ash are considered. Methods of ascertaining the amount of unburnt fuel in ash and clinker from gas producers are described and the economic aspects of the separation of useless clinker from that containing unburnt carbon are discussed. —R. A. R.

Increases in the Combustion-Temperature of Blast-Furnace Gas Due to Oxygen-Enriched Air. M. Steffes. (Revue Technique Luxembourgeoise, 1946, vol. 38, Apr.–June, pp. 4–8). The results obtained by enriching combustion air are discussed with mathematical data showing the relationship of the temperature of combustion to the amount of oxygen in the mixture. The decrease in volume of combustion products is also noted.—R. F. F.

Blast-Furnace Gas Storage at Scottish Steelworks. (Iron and Coal Trades Review, 1947, vol. 155, July 18, pp. 123–124). A detailed description is given of a 2,000,000-cu. ft. constant-pressure waterless gas-holder installed for the storage of blast-furnace gas from the existing furnaces at the Gartsherrie works of Bairds and Scottish Steel, Ltd.—J. R.

Fuels for Open-Hearth Furnaces. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1945, Jan., pp. 1–6). Producer gas, mixed gas, and coke-oven gas, used for heating open-hearth furnaces in France, are discussed.—R. F. F.

Pumps and Control Gear for Oil-Fired Open-Hearth Furnaces. D. C. Hagen. (Iron and Coal Trades Review, 1947, vol. 155, July 25, pp. 157–160, 166). Practical information on the types of pumps and equipment required for supplying fuel oil to the burners of oil-fired open-hearth furnaces is presented.—R. A. R.

REFRACTORY MATERIALS

Manufacture of Refractories—Report of Interrogation of Herr Eric Schroth of Didier Werke, G.m.b.H., Niederdollendorf. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1364: H.M. Stationery Office). A full record is given of the interrogation of E. Schroth on the subjects of plant and techniques used by the German refractories industry, with particular reference to the new plant at Niederdollendorf.—C. O.

Concentration and Determination of Grade in Tests on Sillimanite in Idaho Schist. K. G. Skinner and H. J. Kelly. (Journal of the American Ceramic Society, 1947, vol. 30, July 1, pp. 197–202). Laboratory tests have shown that the 7·8% of sillimanite in a schist from Troy, Latah County, Idaho, may be effectively concentrated by crushing to 35-mesh, washing on a Wilfley slime table, and froth flotation at *p*H 10.—C. O.

A Statistical Sampling Plan for Refractory Products with Special Reference to Silica Bricks. W. T. Hale. (Transactions of the British Ceramic Society, 1947, vol. 46, June, pp. 147–160). **Statistical Consideration in Sampling Silica Bricks.** W. T. Hale. (Iron and Coal Trades Review, 1947, vol. 155, July 11, pp. 5–59). Sampling requirements in the acceptance testing of silica bricks are discussed, and a sampling plan based on statistical considerations is developed.—J. R.

The Stability of Carbon Bricks in Carbon Monoxide. W. T. Howie and J. Mackenzie. (Transactions of the British Ceramic Society, 1947, vol. 46, July, pp. 161–173). An investigation of the action of carbon monoxide on experimental carbon bricks containing metallic iron and ferric oxide and on three commercial brands of carbon brick is reported. The test consisted of passing carbon monoxide, free from oxygen, carbon dioxide, and water vapour, at the rate of 5 litres/hr. over the specimen for 30 hr., the temperature being maintained at 450° C. Each test was repeated using moist carbon monoxide, as this was found to increase the rate of carbon deposition. The commercial bricks were found to be stable under the conditions described. Metallic iron appeared to be a catalyst for the dissociation reaction $2CO \rightarrow C + CO_2$, especially in the finely divided state, as for instance when formed from the reduction of ferric oxide. The bricks containing ferric oxide additions disintegrated much more rapidly than those to which metallic iron was added.—C.O.

Reactions Occurring in Refractory Materials Involving Ferrous Oxide and Magnesia. G. H. B. Lovell, G. R. Rigby, and A. T. Green. (Bulletin of the British Refractories Research Association, 1944, June, No. 67 : Transactions of the British Ceramic Society, 1947, vol. 46, July, pp. 200–206). The reactions between ferrous oxide and magnesia spinel, $MgO.Al_2O_3$, picrochromite, $MgO.Cr_2O_3$, and forsterite, $2MgO.SiO_2$, at temperatures up to 1400° C., have been studied. All the reactions are shown to be strictly reversible and to involve mutual replacement of the ions $Mg^{\cdot\cdot}$ and $Fe^{\cdot\cdot}$. They are considered to be of great importance in the action of ferrous oxide slags on chrome or forsterite refractories. In an appendix an X-ray study of the products of the reaction $2FeO.SiO_2 + 2MgO \rightleftharpoons 2MgO.SiO_2 + 2FeO$ at 1200° and 1400° C., is reported by W. F. Ford.—C. O.

Comparison of Tests for Bulk Density of Fired Ramming Materials and a Description of a Test for Magnesite-Slag Mixes. R. B. Snow and C. E. Sumpter. (National Open-Hearth Conference of the American Institute of Mining and Metallurgical Engineers, 1947, vol. 14, July, pp. 994–998).

Development of Zirconia Resistant to Thermal Shock. C. E. Curtis. (Journal of the American Ceramic Society, 1947, vol. 30, June 1, pp. 180–196). The results of tests of the linear expansion and thermal-shock resistance of binary and ternary combinations with zirconia of the oxides CaO, MgO, CeO_2, ThO_2, and BeO (all of which tend to suppress the zirconia inversion at 1000° C.) are presented. In all the systems investigated which gave good thermal-shock properties, a small amount of inversion was retained.—C. O.

Quality of Foundry Refractories in English Steelworks. J. Ernould. (Revue Technique Luxembourgeoise, 1947, vol. 39, Jan.–Mar., pp. 16–21). The composition and quality of different refractory bricks, used to line large ladles, runners, and nozzles are given. Bricks with a melting point of 1520° C., are considered adequate to line 80-ton ladles holding steel at temperatures of over 1600° C.—R. F. F.

High-Porosity Dolomite Bricks, Parts I and II. A. A. Chadeyron and W. J. Rees. (Bulletin of the British Refractories Research Association, 1940, May, pp. 8–12 ; Sept., pp. 270–275 : Transactions of the British Ceramic Society, 1947, vol. 46, June, pp. 125–132). It has been found that a material of low bulk density, high porosity and refractoriness, adequate mechanical strength, and very low thermal conductivity in the fired state, may be produced by mixing 14% of silica and 2% of a stabilizer with raw dolomite. Experiments have been carried out with various oxides and salts as stabilizers. A particular study was made of the properties of mixtures containing 2% of borax.—C. O.

Combined Use of Silica and Semi-Silica Bricks in Modern Coke-Ovens. (Revue de l'Industrie Minérale, Mémoires, 1947, June, pp. 355–358.) The use of silica with semi-silica bricks may be justified by the present shortage of silica bricks, but leads to difficulties due to their susceptibility to cracking and spalling.—R. F. F.

Study of Colloidal Clays—"Bentonite." M. Guedras. (Revue de l'Industrie Minérale, Mémoires, 1943, Apr., pp. 241–254). This paper describes Centonite, its properties, and industrial uses, and includes a short bibliography.—R. F. F.

Properties and Performance of Blast-Furnace Hearth Refractories. H. M. Kraner. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, 1946, Apr., pp. 40–52). The first part of the paper deals with properties of American fireclays and blast-furnace refractories. The second part describes an investigation of the causes of a blast-furnace rising 4½ in. off the mantle columns, and the hearth jacket breaking after 25 days operation on iron and nine months on ferromanganese.—R. A. R.

The Properties and Applications of Refractory Materials. G. van Gijn. (Metalen, 1947, vol. 1, Aug., pp. 217–224). [In Dutch].

Refractory Economy in Steel Mill Furnaces. E. N. Hower. (Iron and Steel Engineer, 1947, vol. 24, July, pp. 35–38). Examples are given of problems with refractories raised by changing methods of heating reheating furnaces in steelworks, *e.g.*, the use of positive atmospheric pressures and oil-firing. Alterations in furnace design and higher-quality refractories are often needed to offset the increase in costs brought about by changed combustion practice.—C. O.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Development of the Blast Furnace in Luxemburg. A. Peters. (Revue Technique Luxembourgeoise, 1947, vol. 39, Apr.–June, pp. 56–72). Design of blast-furnaces has been modified, in order to save man-power and coke. Further savings are considered possible by improvements in the hearth.—R. F. F.

Our Future Blast Furnace. L. Krotkiewics. (Hutnik, 1946, No. 1, pp. 25–30). [In Polish]. A description is given of a special and economical type of blast-furnace which it is proposed to erect in Poland to increase the annual steel output to 250 kg. per head of population.—W. J. W.

Blast Furnace Bell Development. T. H. Kennedy. (American Iron and Steel Institute, May, 1947, Advance Copy). The considerations which led to the design of a serrated bell for a blast-furnace at McKeesport, Pennsylvania, are outlined. The bell, for a furnace of 19-ft. throat dia., has six radial serrations of 10¼-in. horizontal depth at 60° intervals around its circumference, the bell diameter being 14 ft. across the crests and 12 ft. 3½ in. across the troughs of the serrations. The bell is rotated 10° each time it is closed. It has proved extremely satisfactory in service over a period of three years.—C.O.

A Design for Blast Furnace Hearths. W. S. Unger. (American Iron and Steel Institute, May, 1947, Advance Copy). The calculation of the dimensions and the choice of materials for the hearths of blast-furnaces are discussed. Points of operation which may neutralize the advantages of good design and use of the best materials are mentioned. —C. O.

Cooler Modification. (Iron and Steel, 1947, vol. 20, July, p. 356). A modified design of blast-furnace cooler is illustrated. It is claimed to give a sealed joint with the furnace brickwork, thus preventing gas leaks, and to be easily and rapidly removable.—C. O.

The Replacement of Air by Oxygen in Metallurgical Operations. P. Guillaumeron. (Génie Civil, 1947, vol. 124, Mar. 1, pp. 85–86). This is a review of the progress in the use of oxygen in the blast-furnace, Bessemer converter, and open-hearth furnace.—R. F. F.

American "Pressure-Blowing" Methods for Blast Furnaces. (Iron and Coal Trades Review, 1947, vol. 155, Aug. 22, pp. 365–366). High top-pressure operation of blast-furnaces is discussed with special reference to its advantages in permitting the efficient use of a higher proportion of fines in the burden. The results of full-scale trials in America reported by J. H. Slater (*see* Journ. I. and S.I., 1947, vol. 157, Sept., p. 141). are reviewed. It is suggested that the technique could be applied to Lincolnshire and Northamptonshire ores. —R. A. R.

Closer Control of Blast Furnaces Through Increased Instrumentation. W. Flanagan. (Instrument Society of America : Industrial Heating, 1947, vol. 14, July, pp. 954–960). Those quantities and conditions in blast-furnace operation which it is necessary to measure continuously in order to maintain close control are indicated.—C. O.

Utility and Technique of Control Measurements in a Blast-Furnace Plant. A. Arnould. (Publications de l'Association des Ingénieurs de la Faculté Polytechnique de Mons, 1946, vol. 94, No. 1, pp. 8–14 ; No. 2, pp. 24–30). The author discusses the relative importance of the weight and composition, physical properties, and level of the charge in blast-furnace operation, the flow, pressure, and temperature of the blast and of the gases at the top of the furnace. Factors affecting stoves are also considered.—J. C. R.

A Method of Estimating Blast Furnace Production and Coke Consumption. W. E. Marshall. (American Iron and Steel Institute, May, 1947, Advance Copy). A method for estimating the effect on production and coke consumption of a change in blast-furnace operating practice is explained, with numerical examples of the calculations involved. The basis of the method is a comparison of the proposed process with a standard process for which all the data are known, *i.e.*, the previous performance of the furnace. In an appendix simultaneous equations for estimating the amounts of coke consumed at the tuyeres and in the stack are derived.—C. O.

Mobile Pig-Casting Machine. (Engineering, 1947, vol. 164, Aug. 22, pp. 176–177). A pig-casting machine for iron and non-ferrous metals is described and illustrated. The machine is mobile and its speed can be adapted, when casting pigs of 28 lb. weight, to give an output of 30 cwt./hr., with a cooling time of 17 min. per pig, or 182 cwt./hr., with a cooling time of 2¾ min. per pig. An oil-fired 1-ton reverberatory tilting furnace for use in conjunction with the machine is also described. —C. O.

Cupolas for the Synthetic Production of Pig Iron. H. Reiniger. (Technik, 1947, vol. 2, July, p. 337). A description is given of a cupola which works on 6-day campaigns for the production of pig iron. The melting zone is lined with 6 in. of silica brickwork. Water-cooling is provided from 6 in. above the bottom plate to 6 in. above the melting zone. The slag notch is also provided with water-cooling.—R. A. R.

A Tapping-Hole Survey. D. P. Cromwell. (American Institute of Mining and Metallurgical Engineers, Blast Furnace and Raw Materials Conference, 1946, Apr., pp. 60–64). This paper summarizes the information obtained in replies to a questionnaire on blast-furnace taphole practice.—R. A. R.

DIRECT PROCESSES AND PRODUCTION OF WROUGHT IRON

Control of Sulphur Content of Sponge Iron Produced in Rotary Kilns. R. C. Buehl, E. P. Shoub, and J. P. Riott. (United States Bureau of Mines, 1947, Report of Investigations, No. 4057). This report describes pilot-plant tests in the reduction of iron-ore in the rotary kiln that were performed at Johnstown, Pennsylvania, and rotary-kiln tests in connection with this project at the Central Experimental Station of the Bureau of Mines.—R. A. R.

Pilot-Plant Investigations. Production of Sponge Iron with Producer Gas. D. R. Torgeson, T. E. Evans, and R. G. Knickerbocker. (United States Bureau of Mines, 1946, Report of Investigations No. 3994). Experimental development work on a pilot-plant scale has shown that sponge iron can be produced in the multiple-hearth furnace by reduction with gas of relatively low quality, subject to certain operational limitations. Trials with the object of producing a satisfactory process are reported. —R. A. R.

Investigation of Bubble-Hearth Process for Production of Sponge Iron. E. P. Barrett, C. E. Wood, V. Miller, W. E. Brown, P. R. Porath and C. Prasky. (United States Bureau of Mines, 1947, June, Report of Investigations No. 4092). An account is given of investigations of the possibility of producing sponge iron by passing hot hydrogen through bubble caps into a bed of iron ore on a flat, circular, hollow hearth. The process was found to be unworkable because of the difficulty of maintaining the bed in a sufficiently fluid state for the deoxidized material to pass from the hearth, and because of the dust losses arising from the fineness of the ore required (−48 mesh).—C. O.

Production of Low-Sulphur Sponge Iron. R. C. Buehl, E. P. Shoub, and J. P. Riott. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2093: Metals Technology, 1946, vol. 13, Oct.). A description is given of an investigation into the distribution of sulphur in sponge-iron particles formed by the reduction of ore in a rotary kiln containing coke made from coal and pulverized limestone, and powdered burned lime. It was found that all the sulphur in excess of 0·02–0·03% was present in a surface layer on the iron particles. This sulphur-bearing layer was not formed when graded dolomite was used to control the sulphur content of the charge.—C. O.

PRODUCTION OF STEEL

Modernisation of the Iron and Steel Industry. (Man and Metal, 1947, Aug., pp. 118–119). Details are given of modernization schemes now in hand at the Consett Iron Works and the Construction Department and the Cleveland Works of Messrs. Dorman Long & Co., Ltd.

Present-Day Problems for Our Metallurgical Works. A. G. Lefebvre. (Publications de l'Association des Ingénieurs de la Faculté Polytechnique de Mons, 1946, vol. 94, No. 2, pp. 5–14; No. 3, pp. 1–10). This is the second part of a series and it deals with steelworks problems. Methods for improving the quality of basic Bessemer steel are considered, with particular reference to the H.P.N. (Hamborn phosphorus-nitrogen) process which enables a steel low in phosphorus and nitrogen to be obtained. The basic-Bessemer-converter/basic-electric-furnace and Perrin duplex processes and their industrial applications are reviewed.—J. C. R.

Manufacture of Mild Steel. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1945, Sept., pp. 111–116; Oct., pp. 121–129). Eight different methods of steelmaking using the acid and basic Bessemer processes, and the acid and basic open-hearth and duplex processes are described, with special reference to the use of metallic materials and the quantities of slag.—R. F. F.

Steel-Melting Trials with Oxygen-Blast in the Bessemer Converter at the Stalin Kutnetzk Metallurgical Combine. V. V. Kondakov. (Iron and Steel Institute, 1947, Translation Series, No. 316). This is an English translation of a paper which was published in Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques, 1946, No. 10, pp. 1401–1420.—D.R.S.

The Metallurgy of Refining with Molten Slags. R. Perrin. (Revue de l'Industrie Minérale, Mémoires, Jan.–Feb., pp. 7–13). Improvement in basic-Bessemer steels obtained by the Perrin process are described. Steels of high quality are obtained by a close control of the chemical analysis of the slag. The pre-melting of the slag in a separate furnace speeds up the process and increases the life of linings.—R. F. F.

Basic-Bessemer Steel between 1927 and 1947. N. Mousel. (Revue Technique Luxembourgeoise, 1947, vol. 39, Apr.–June, pp. 74–85). The improvements made in the production of basic-Bessemer steel during the years 1927–1947 are noted.—R. F. F.

The All-Basic Open-Hearth Furnace. J. E. Pluck. (Iron and Coal Trades Review, 1947, vol. 155, Aug. 8, pp. 257–265). After an account of the advantages and disadvantages of the all-basic type of steel furnace, the construction of such furnaces is discussed, particular emphasis being given to the problem of roof design.—C. O.

Use of Sponge Iron in Steel Production. R. C. Buehl, M. B. Royer, and J. P. Riott. (United States Bureau of Mines, 1947, July, Report of Investigations No. 4096). A short account is given of the manufacture and properties of sponge iron, and the literature on its use in steel production is reviewed. A report is made on a series of experiments with the replacement of scrap by sponge iron during normal production at a number of acid and basic open-hearth and electric steel furnaces. These furnaces were mostly of less than 40 tons capacity and were producing low- and high-carbon steels, and alloy and stainless steels, to be fabricated by rolling, forging, or casting. It is concluded that sponge iron can be used to replace scrap without change in the method of operation or reduction in capacity of the furnace, to an extent dependent upon the grade of the iron, the type of furnace, and the furnace practice. The physical properties of steels made partly from sponge iron are as good as those of steels of comparable analysis made from normal raw materials.—C. O.

Items of Controllability in the Open Hearth Combustion Process. A. J. Fisher. (American Iron and Steel Institute, May, 1947, Advance Copy). The instruments used in controlling the basic open-hearth furnaces at the Sparrows Point plant of the Bethlehem Steel Company are described and illustrated in detail.—C. O.

Installation and Use of Instruments on Open-Hearth Melting Furnaces. R. C. Baker. (Journal of the Iron and Steel Institute, 1947, vol. 157, Sept., pp. 81–88). The installation and development of recording and control instruments for routine use in a small open-hearth plant are described. Features of the system are the recording of the furnace-roof temperature and the gas and air flows on one chart, also an experimental automatic crown-temperature control. The instruments have proved of great value to the operators, and have increased the melting rates.

Relation of Flame Character to Open-Hearth Operation. A. J. Fisher. (American Institute of Chemical Engineers, Symposium on Radiant Energy and Gaseous Reaction : Industrial Heating, 1947, vol. 14, June, pp. 909–912). The theoretical aspects of the components making up total flame radiation and practical methods of controlling flame radiation in the open-hearth furnace are discussed. —R. A. R.

Oxygen Jet Speeds Open-Hearth Steel Output. (Iron Age, 1947, vol. 159, June 19, pp. 75–76). A short description is given of the use of a jet of oxygen at high velocity for rapidly melting preheated scrap and for removing the carbon in open-hearth melts.—C. O.

Notes on Swedish Acid Openhearth Practice. S. M. Wejle. (Iron Age, 1947, vol. 160, July 3, pp. 67–68). Swedish acid open-hearth steel owes its very high quality to the purity of the raw materials and the close control exercised during its melting, usually in small furnaces of not more than 20 tons capacity. The outstanding properties of such steel are its elasticity and fatigue resistance, and it therefore finds its main applications in such products as ball bearings, cold-rolled and hardened strip for saws and springs, and parts for hosiery machinery. —C. O.

Use of Oxygen in Combination with Open-Hearth Furnace Steel. H. M. Griffith. (American Institute of Mining and Metallurgical Engineers : Industrial Heating, 1947, vol. 14, July, pp. 692–964). Experiments with oxygen-enriched air combustion in a 175-ton open-hearth steel furnace are described.—C. O.

Direct Oxidation. E. B. Hughes. (American Institute of Mining and Metallurgical Engineers : Blast Furnace and Steel Plant, 1947, vol. 35, June, pp. 677–686). Details are given of direct oxidation in the open-hearth furnace by means of pure oxygen piped into the bath at a pressure of about 100 lb./sq. in. The application is considered to have passed the experimental stage and has resulted in a decrease of heat time, an increase in temperature, and a saving of fuel.—J. R.

The Use of Oxygen in the Open Hearth Practice for Carbon Reduction. G. V. Slottman and F. B. Lounsberry. (American Iron and Steel Institute, 1947, Preprint). Studies of the factors affecting the rate of carbon removal from the open-hearth steel bath were made during large-scale trials with the use of direct gaseous oxygen additions by the Allegheny Ludlum Steel Corporation in 1946. Data are presented on the efficiencies calculated for various oxygen-blowing rates and bath carbon contents. The average bath oxygen content was found to be within the common limits for normal slag/metal practice ; the slag oxygen content varied inversely with the bath carbon content and appeared to be affected by the rate of blowing. The major influences on the rate of carbon and manganese removal are considered to be the effect of oxygen entering the slag from the metal and the "diffusion factor," $(O_s–O_c)$, where O_s is the oxygen content of steel at saturation and O_c is the oxygen content corresponding to equilibrium at the given carbon content. An equation for the rate of carbon removal is derived and criticized. It is concluded that the time of blowing and weight of oxygen supplied can be predetermined to reduce the carbon between any desired limits. Production experience indicates that increases in output of the order of 25%, with increased yield and equal or better quality are obtained with oxygen reduction as compared with slag/metal practice.—C. O.

Low Cost Oxygen for Metallurgical Uses. W. E. Lobo. (Iron Age, 1947, vol. 160, July 17, pp. 49–53). The development during the war of a process for producing oxygen by fractionation at low pressures is described and the adaptation of the process for metallurgical use is discussed. It is thought that in a plant producing 400 tons of oxygen per day the cost might be as little as $3.50 per ton.—C. O.

Selection and Application of Statistical Methods to Steel Plant Processing Problems. E. L. Robinson and L. G. Eckholm. (American Iron and Steel Institute, May, 1947, Advance Copy). The application of statistical methods in steelworks is illustrated by simple numerical examples relating to the performance of different types of checker brick.—C. O.

Notes on the Killing of Steel. G. Husson. (Revue de l'Industrie Minérale, Mémoires, 1946, July, pp. 325–338). The effect of additions such as silicon, aluminium, and titanium, on the killing of steel is described. Methods for killing different kinds of steels are also discussed. —R. F. F.

Introduction to the Scientific Study of the Refining of Steel. F. Fer. (Revue de l'Industrie Minérale, Mémoires, 1947, Apr., pp. 175–190). The aim of this study is to develop equations to cover the process of refining steel, and means of solving these equations.—R. F. F.

The Action of Carbon as a Reducing Agent in the Reactions of the Steelmaking Processes with Acid Slags. F. Körber and W. Oelsen. (Iron and Steel Institute, 1947, Translations Series, No. 315). This is an English translation of a paper which was published in Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1935, vol. 17, No. 4, pp. 39–61. (*See* Journ. I. and S.I., 1935, No. II, p. 382).—D. R. S.

Electric Apparatus for Three-Phase Arc-Furnaces. N. R. Stansel and A. R. Oltrogge. (Electrochemical Society, 1947, Preprint No. 91-25). After an introductory discussion of the arc-furnace circuit and load, the functions of the electric apparatus involved are outlined. The main part of the paper gives descriptions of present-day electric apparatus for three-phase arc-furnace installations.—D. R. S.

Electric Furnace Rimmed Steel. D. I. Brown. (Iron Age, 1947, vol. 160, Aug. 7, pp. 67–69, 149). A detailed account is given of the practice at the South Chicago Works of the Carnegie-Illinois Steel Corporation, where low-carbon rimming steel is being made in 80-ton Héroult furnaces. The charge is all scrap, and carbon reduction is accomplished solely by the use of the oxygen lance. Oxygen is directed at a pressure of 80–90 lb./sq. in. on the surface of the bath, as soon as sufficient liquid has been formed, through a $\frac{1}{2}$-in. steel pipe wrapped in wet ganister. Precise slag control is unnecessary, and the total slag volume (only one slag is used) is very low compared with open-hearth practice. The average time from tap to tap is 7 hr.—C. O.

Production of Electric Furnace Electrodes. L. C. Judson. (Iron Age, 1947, vol. 160, Aug. 14, pp. 62–64). The steps in the production of carbon and graphite electrodes for melting furnaces from coal and petroleum coke are illustrated.—C. O.

Slags in the Production of Iron and Steel. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1945, Mar., pp. 21–25 ; Apr., pp. 41–45 ; May, pp. 55–60 ; June, pp. 75–79 ; July, pp. 93–98). This is a general review of the rôle of slags in steelmaking with examples and analyses.—R. F. F.

Slag-Metal Reactions in the Open-Hearth Furnace. M. G. Husson. (Revue de l'Industrie Minérale, Mémoires, 1945, Aug., pp. 289–315). The SiO_2–CaO–FeO(MnO) ternary diagram is studied and certain conclusions are deduced from it.—R. A. R.

Molecular Constitution of Open-Hearth Slags and the Distribution of Oxygen and Sulphur in the Slag–Metal System. A. C. Heinman. (Iron and Steel Institute,

1947, Translation Series, No. 317). This is an English translation of a paper which was published in Bulletin de l'Académie des Sciences de l'URSS, Classe des Sciences Techniques, 1946, No. 10, pp. 1439–1458.—R.A.R.

The Mineralogy of Basic Open-Hearth Slags. J. L. Mauthe and K. L. Fetters. (American Iron and Steel Institute, May, 1947, Advance Copy). Data, obtained from contemporary literature on the constitution of the binary and ternary systems found in basic open-hearth slags and on the optical properties of solid phases are presented. The petrography of slags is illustrated by numerous coloured photographs.—C. O.

X-Ray Diffraction Studies of Chrome-Steel Slags. G. P. Chatterjee and S. S. Sidhu. (American Society for X-Ray and Electron Diffraction and Electron Microscope Society of America: Journal of Applied Physics, 1947, vol. 18, June, pp. 519–521). A study by X-ray diffraction methods of the crystalline constituents of natural and synthetic slags used when making acid open-hearth chromium steel is reported. Chromium was found to be present as a spinel in the form $FeO.Cr_2O_3$, with a density of 5·109 g./c.c., and a melting point of 2160° C., with a face-centred cubic structure of unit-cubic-cell length 8·348Å, and containing 8 molecules per unit cell.—C. O.

Contribution to the Study of Solidification of Rimming Steels. G. Husson. (Revue de l'Industrie Minérale, Mémoires, 1946, Mar., pp. 111–134). The theory advanced by the author is that a good rimming steel can be obtained by: (1) Refining with a basic slag containing 35–37% of MnO + FeO; (2) bringing the carbon down to 0·06–0·07% max., with the addition of ferromanganese to obtain 0·075% of carbon and 0·3% of manganese; (3) pouring slowly at comparatively low temperature; and (4) making small additions of aluminium to the mould.—R. A. R.

Influence of the Character of Crystallization and the Period of Crystallization on the Mobility of Molten Metal between Growing Crystals. A. A. Bochvar and V. V. Kuzina. (Iron and Steel Institute, 1947, Translation Series No. 313). This is an English translation of a Russian paper which was published in Bulletin de l'Académie des Sciences de l'URSS, Classes des Sciences Techniques, 1946, No. 10, pp. 1459–1462. Based on analogous phenomena observed during the crystallization of copper–aluminium alloys, it is pointed out that a great amount of molten metal may be trapped between dendritic crystals during the solidification of steel ingots. This leads to the conclusion that the method of investigating the rate of crystallization of steel by tipping the mould at certain intervals and pouring out the part of the metal not yet crystallized leads to erroneous results.—D. R. S.

The Metallurgy of Cold Reduced Sheets. C. L. Altenburger. (American Iron and Steel Institute, May, 1947, Advance Copy). The theory and practice of the production of rimming steel are outlined. Segregation, in particular the effect of sulphur, strain-ageing, and deoxidation are also discussed. A chart is presented showing the effect of cold-reduction and annealing temperature on the microstructure of steels.—C. O.

FOUNDRY PRACTICE

New Automotive Foundry Engineered on Assembly Line Pattern. (Foundry, 1947, vol. 75, July, pp. 80–85, 240–241). An illustrated description is given of the reorganized foundry of the Cadillac Motor Car Division of the General Motors Corporation. The foundry is designed on the assembly-line principle and great attention has been paid to the health and well-being of the workers by the elimination of heavy manual labour and the provision of special ventilation and lighting. —C. O.

German Piston and Piston Ring Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 301: H.M. Stationery Office).

"Synthetic Cast Irons" and Substitute Foundry Fuels. M. Guédras. (Revue de l'Industrie Minérale, Mémoires, 1942, Nov., pp. 285–292). In view of the availability of hydro-electric power in France, it is recommended that greater use be made of the electric furnace, for the melting of cast iron, and that foundries in the west of France try to substitute peat, found locally, for coke.—R. F. F.

Foundry Coke Characteristics and Quality Factors. D. E. Krause and H. W. Lownie, jun. (American Foundryman, 1947, vol. 11, July, pp. 49–58). The literature on the testing of foundry coke is critically reviewed. The difficulty in correlating test results with actual cupola performance is illustrated by data obtained in an investigation at the Gray Iron Research Institute, Incorporated. One hundred and forty-three references are contained in the appendix.—C. O.

Confirmation of Coefficient of Heat Transfer in a Cupola, and Time Required to Heat and Melt the Metal. N. Czyzewski. (Annales de l'Académie Polonaise des Sciences Techniques, 1939–1945, vol. 7, pp. 49–62). Formulæ are derived for: (*a*) The coefficient of heat transfer from gases to metal in a cupola; (*b*) the time required to raise the metal to the melting point; and (*c*) the distances above the tuyere level at which fusion begins and ends. These equations are applied to calculate the maximum size of pieces which can be melted under practical conditions.—R. A. R.

Finishing and Inspection—Mechanized Malleable Foundry. D. F. Sawtelle. (American Foundryman, 1947, vol. 11, June, pp. 44–46; American Foundryman's Association, Preprint No. 47-24). The barrel-tumbling, steel-shot blasting, grinding, and shearing equipment of a mechanized malleable iron foundry is briefly described.—C. O.

Graphitization of Cast Irons of Pearlitic Structure. M. Guédras. (Mécanique 1946, vol. 30, Apr., pp. 97–98). Investigations were made with the object of producing at a reasonable cost, after an anneal of short duration, a high-quality pearlitic cast iron. A chromium iron with a very fine pearlitic structure was obtained.—R. A. R.

Practical Aspects of Gray Iron Inoculation. E. V. Somers and D. W. Gunther. (Iron Age, 1947, vol. 160, Sept. 4, pp. 72–75). The objects, applications, and effects of the inoculation of cast iron are explained from the point of view of the practical foundryman.—C. O.

The Production of Carbon and Alloy Steels by the Side Blown Converter Process. F. Cousans. (Institute of British Foundrymen, June, 1947, Paper No. 878: Foundry Trade Journal, 1947, vol. 82, July 24, pp., 275–280; British Steelmaker, 1947, vol. 13, July, pp. 341–349). Detailed descriptions are given of the side-blown converter processes of making carbon and alloy steels. The high degree of control obtainable with the photo-electric cell and the quick-immersion thermocouple is stressed. Steel of very high quality has been produced by the process in recent years as is shown by the test data which are given. The 25-ton basic side-blown converter has been very successful.—R. A. R.

Producing Steel Castings by the Thermit Process. R. C. Wayne. (Foundry, 1947, vol. 75, Aug., pp. 84–87, 204–214). The development by the United States Navy of a technique for making steel for castings by the thermit process is described.—C. O.

Mass Production Methods Applied to the Manufacture of Cast Steel Bomb Bodies. P. H. Wilson. (Institute of British Foundrymen, June, 1947, Paper No. 879). A highly mechanized steel foundry for the mass production of 500-lb. bomb bodies in green-sand moulds is described; the operations include the production of steel in side-blown converters from metal consisting entirely of cupola-melted steel scrap—R. A. R.

Surface Quality in Alloy-Steel Castings as Affected by Sand Mixtures and Mould Washes. H. E. Crivan. (Metal Treatment, 1947, vol. 14, Summer Issue, pp. 84–92). Tests of the effect of various sand mixtures and mould washes on the condition of the surface of alloy-steel castings are described. The tests were made on moulds arranged in batches of six in circles, the runners being connected to a common central downgate to ensure identical casting conditions for each mould. It was found that scabbing can be caused by a deficiency in clay content and defects such as pitting by an excess of clay in the sand. The dimensions and shape of the casting influence the tendency for scab formation. Synthetic sand mixtures gave better surfaces than naturally occurring sands in general. "Silica paint" proved the best of the common inexpensive mould washes.—C. O.

Steel Casting Design Details Affect Quality of Product. F. Kiper. (Product Engineering, 1947, vol. 18, Aug., pp. 86–89). A simple method of applying the principles of directional solidification to the design of steel castings is explained. The temperature gradient may be divided into a transverse component, and a longitudinal or "section" component, each of which can be utilized in improving casting quality.—C. O.

Study of Sands Used in Steel Foundries. M. Guédras. (Revue de l'Industrie Minérale, Mémoires, 1945, May, pp. 149–162). The composition, properties, and preparation of sands for steel foundries are described.—R. F. F.

New Process Chemically Treats Molding Sand. T. W. Curry. (American Foundryman, 1947, vol. 11, June, pp. 51–56). The advantages of using moulding sands chemically treated with the proprietary compound Westonite are enumerated.—C. O.

A Study of the Behavior of Molding Sands when in Contact with Liquid Steel. J. B. Caine. (Steel Founders' Society of America: Foundry, 1947, vol. 75, July, pp. 72–77, 143–158). Investigations of the effect of radiant heat and immersion in liquid steel on the behaviour of moulding sands of different compositions and properties are reported. Data are given for the influence on scabbing and spalling of degree of ramming, water content, reclamation, drying, and organic additions. —C. O.

Molding Sands—Physical Properties. G. R. Gardner. (American Foundryman, 1947, vol. 11, June, pp. 34–38). The effect on the properties of moulds of variations in moisture content and ramming energy has been investigated experimentally. Charts are presented showing the influence on green compressive and tensile strength, resistance to deformation, surface hardness, and apparent density of various combinations of the two variables.—C. O.

Use of Cement in Foundry Sands—Application of the Randupson Process. M. P. Herrgott. (Revue de l'Industrie Minérale, Mémoires, 1942, Dec., pp. 325–332). Foundry sands containing cement are found suitable for large castings of both iron and steel. The greater strength of the mould and the rapidity of drying offer great advantages over ordinary sands.—R. F. F.

Foundry Sand Reclamation. J. M. Cummings and W. M. Armstrong. (American Foundryman, 1947, vol. 11, July, pp. 35–39, 65). A report is presented on the first phase of a research programme sponsored by the British Columbia Research Council to determine the possibility of reclaiming steel-foundry sands. As a result of experiments with a combined wet-scrubbing, classification, and calcining process it is concluded that it is practical to reclaim sand economically even in relatively small foundries.—C. O.

Making Plastic Patterns. E. J. McAfee. (American Foundryman, 1947, vol. 11, July, pp. 26–31). The technique of making patterns and core boxes of thermosetting phenolic resin is described.—C. O.

Plastic Patterns. R. H. Herrmann. (Foundry, 1947, vol. 75, July, pp. 89, 232–233). The application of thermosetting phenol-formaldehyde resins for making matchplates and duplicates of master pattern, is described. —C. O.

Gates and Risers—Calculation of Sizes. N. Janco. (American Foundryman, 1947, vol. 11, June, pp. 57–60; American Foundrymen's Association, Preprint No. 47-48). The application of a method for calculating the sizes of gates and risers of centrifugal castings to similar calculations for static castings is explained.—C. O.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Heat-Treatment of Chains. M. G. van der Steeg. (Metalen, 1947, vol. 1, June, pp. 190–192; July, pp. 207–209). [In Dutch].—R. A. R.

Heat Treatment of Heavy Cast Steel Sections. P. C. Rosenthal and G. K. Manning. (Steel, 1946, vol. 119, Nov. 18, pp. 88–94, 111). An account is given of investigations on the complete hardening of heavy sections of cast steel. Cooling rates experimentally determined at the centre and half-way between the centre and surface of 6-in. thick plates during water-quenching and air-cooling were in agreement with those calculated from published data. There was only a slight difference in the cooling rates at the centre and half-way to the centre of the water-quenched plates. A special end-quench hardenability test-specimen was devised to cover the range of cooling rates beyond the lower limit of the standard test. It was found from a study of isothermal transformations in alloy steels that the amount of alloy which can usefully be added to steels to be quenched in heavy sections is limited by: (1) The tendency for crack formation during quenching; (2) susceptibility to temper brittleness; (3) difficulty in obtaining readily machinable structures.—C. O.

Planning a Toolroom Heat-Treating Department. R. C. Onan. (Iron Age, 1947, vol. 160, July 31, pp. 40–44; Aug. 7, pp. 70–77). The capacities and applications of various sizes and types of heat-treatment and brazing furnaces are considered from the viewpoint of the design of a department for heat-treating tools. Data are given on the capital cost and space requirements of several suggested layouts.—C. O.

Various Types of Heat Treating Handled in One Installation. (Steel, 1947, vol. 121, July 21, pp. 99, 142). A battery of six immersed-electrode salt-bath furnaces designed to perform all types of heat-treatments at temperatures from 300° to 2500° F. is described. Tempering, isothermal quenching, and liquid carburizing and cyaniding can be carried out at the rate of 500 lb./hr. in each furnace.—C. O.

Convection Annealing. W. F. Toerge. (Steel, 1947, vol. 121, July 21, pp. 130–140). The convection-annealing equipment used at the Hamilton, Ontario, works of Dominion Foundries and Steel, Ltd., for 46-in. dia. coils of steel strip is described.—C. O.

Carbide and Oxide in Surface Zones of Carburized Alloy Steels. A. Hultgren and E. Hägglund. (Transactions of the American Society for Metals, 1947, vol. 39, pp. 820–839). A series of alloy steels has been heated at 900° C. for 50 hr. in a charcoal/barium-carbonate mixture, in a mildly carburizing compound (Dohundin), and in an atmosphere obtained by passing pure hydrogen through toluene. Photomicrographs of the structure resulting from these treatments in chromium, molybdenum, tungsten, and manganese steels are presented, and show that no carbide zone was formed when the mildly carburizing compound was used. All the steels showed a thin surface zone containing oxide particles and free from carbide particles after pack-carburizing. The manganese steel behaved differently from the others during carburization in the charcoal/barium-carbonate mixture and the gaseous atmosphere.

Theories are developed to explain the formation of carbide and oxide zones in steels of certain alloy contents under defined conditions.—C. O.

Gas Chemistry—Its Role in Metallurgy. O. E. Cullen. (Steel, 1947, vol. 121, July 7, pp. 86–88, 120–124), The uses of controlled atmospheres for recarburizing. carburizing, cyaniding, and bright annealing are briefly surveyed.—C. O.

Controlled Atmospheres in Furnaces. P. Heurtey. (Energie, 1947, vol. 31, June, pp. 151–158). The theory of controlled atmospheres is discussed, and a description of the "Kemp" generator is given.—R. F. F.

Surface Hardening with the Blowpipe. M. Vilez. (Mécanique, 1946, vol. 30, July, pp. 165–170; Aug., pp. 199–203). The use of the oxy-acetylene blowpipe for the surface-hardening of iron and steel is discussed. The methods, tools, materials, and results are described. —R. F. F.

Silicon Carbide Radiant Tubes for Annealing Furnaces. M. H. Luttrop. (Iron Age, 1947, vol. 160, Aug. 14, pp. 58–61). The construction of a furnace for continuously annealing stainless-steel tubes at temperatures up to 2000° F. is described. The furnace is heated by gas-fired silicon carbide radiant tubes, and the hearth, which is 15ft. long and 2 ft. 6 in. wide, is made of water-cooled silicon carbide rolls.—C. O.

Suitable Temperatures and Times for Cycle Annealing. K. O. Nordin and E. Tholander. (Jernkontorets Annaler, 1947, vol. 131, No. 7, pp. 243–258). [In Swedish]. The Research Department of Jernkontoret is studying the possibility of applying the isothermal transformation of austenite after hot-working steel. It is expected that its use will prevent the formation of martensite at many stages of production, that it will produce a good machinable structure and save annealing capacity and fuels. This paper is a survey of the literature up to and including 1946 and it includes a 6-page table giving the analyses and the cycle-annealing temperatures and times for a large number of steels. There are 46 references.—R. A. R.

Practical Examples of the Hardening of Annealed Tools. H. J. Ollendorff. (Technik, 1947, vol. 2, July, pp. 331–334). In Germany many tools recovered from the debris of fires are found to be fully annealed. Descriptions are given of methods by which files and other tools can be tested, cleaned, and rehardened.—R. A. R.

Ingenious Steel Quenching Practices Developed by Farm Implement Makers. K. Rose. (Materials and Methods, 1947, vol. 25, June, pp. 77–80). Heat-treatment and forming methods used in the mass-production of farm implements are described and illustrated. They include: (1) A pressure-quenching device for preventing distortion in plough-shares during quenching; (2) a hand-operated fixture for the selective hardening of plough-share points; (3) the Urschel machine for combined forming and pressure-quenching; and (4) a process for straightening warped harrow discs.—C. O.

Methods for the Quenching of Steel. M. H. Mawhinney. (Industrial Heating, 1947, vol. 14, June, pp. 930–938). This article, the concluding one of a series on modern production quenching methods, contains a discussion of flood and surface quenching techniques.—C. O.

Controlling Physical Properties by the Interrupted Quench. H. E. Boyer. (Iron Age, 1947, vol. 160, July 3, pp. 49–54). The principles of austempering, martempering, and "marquenching" (interrupted quenching without isothermal transformation) are explained and the variations in hardness and toughness obtainable by each of the processes are indicated.—C. O.

Tempering Tool Steels. G. A. Roberts. (Steel, 1947, vol. 121, July 28, pp. 72–74, 98–100; Aug. 4, pp. 96–100). Data on the interrelation of hardness, tempering time, and tempering temperature are presented for: (1) Three high-speed steels—an 18/4/1 tungsten–chromium–vanadium, a 6/5/2 tungsten–molybdenum–vanadium, and a 6/4/4/4 tungsten–molybdenum–chromium–vanadium steel containing 1·25% of carbon, and (2) three cold-working and two hot-working highly alloyed die steels—C. O.

FORGING, STAMPING, DRAWING, AND PRESSING

Fundamentals of Forging. A. Ashburn. (Machinist, 1947, vol. 91, Aug. 16, pp. 505–520). The principles of forging practice are outlined, with illustrations of hammers, presses, the main forging operations, and the design of dies.—C. O.

Shaping and Forming. W. Trinks. (American Iron and Steel Institute, May, 1947, Advance Copy). Aspects of the hot-and-cold forming of metals, such as piercing. the variables affecting deformation, the flow of metal in forging, the influence of friction, and the cold-rolling of strip steel, are briefly discussed.—C. O.

New Mechanised Forge in Sheffield. (Iron and Coal Trades Review, 1947, vol. 155, July 25, pp. 173–176). **A Mechanized Forge.** (Machinery, 1947, vol. 71, July 24, pp. 102–104; Engineer, 1947, vol. 184, July 11, pp. 31–33). An illustrated description is given of the new forging works of Daniel Doncaster and Sons, Ltd., Sheffield. The layout provides up-to-date methods of control for the forging manipulations of high-grade steel ingots under a steam hammer. The working conditions of the men are also very greatly improved. The materials forged include semi-high-speed steel for hot dies, high-speed steel for cutting tools, and high-alloy steels.—R. A. R.

Machining Operations Eliminated by Formed Tubing. (Iron Age, 1947, vol. 159, June 19, p. 59). The economic advantages of producing accurately sized steel bushings and spacers from strip instead of tubing are indicated. —C. O.

Extrusion Method of Manufacturing Tubes. H. Lorant. (Mechanical Engineering, 1947, vol. 69, June, pp. 471–474). The piercing and extrusion of stainless-steel and copper–nickel alloy billets into tubes is illustrated, and the preheating, extrusion speeds, and extrusion tools used in the process are discussed.—C. O.

German Apparatus for Twisting Heavy Forged Steel Crankshafts. (British Intelligence Objectives Sub-Committee, 1947, B.I.O.S. Final Report No. 1329: H.M. Stationery Office).

Some Aspects of Drop Forging. N. J. Sheppard. (Australian Institute of Metals: Australasian Engineer, 1947, June 7, pp. 40–59). A comprehensive survey is made of drop-forging practice, including preforming operations, heat-treatment, and finishing.—C. O.

New Press Operates at 1800 Strokes Per Min. H. E. Linsley. (Iron Age, 1947, vol. 160, July 10, pp. 58–59, 127–128). The operation of a punch press, known as the "Hypermatic," which is capable of working at 1800 strokes/min., is described. The punches and dies are actuated by a rotary motion from four crankshafts, rotating in pairs in opposite directions and each driven by a separate motor. Complete absence of vibration is claimed.—C. O.

Pressworking of Stainless Steels. C. W. Hinman. (Steel Processing, 1947, vol. 33, June, pp. 355–357). A short summary is made of the commercially useful properties of stainless steel, and details of the techniques of fabricating stainless-steel parts by deep-drawing are given.—C. O.

The Pressing of Stainless Steel Exhaust "U" Pipes and Shrouds. T. W. Elkington. (Sheet Metal Industries, 1947, vol. 24, Aug., pp. 1603–1608). The sequence of operations in the pressing of aircraft-engine exhaust pipes and shrouds containing **U**-bends, from stainless-steel sheet, is described and illustrated.—C. O.

Hot-Heading and Cold-Forming Bars in Single Operation. (Iron Age, 1947, vol. 160, July 17, p. 60). A machine for the simultaneous production of a circular flange, a square head, and a 1-in. flat on ¼-in. dia. bars, at the rate of 30/min., is briefly described.—C. O.

Development of Steel for Bolts in Scotland. A. P. Newall. (Wire and Wire Products, 1947, vol. 22, July, pp. 499–503). A short account is given of the pickling plant of Messrs. A. P. Newall and Company, Ltd. Glasgow, and of the development of a process for making high-tensile steel bolts by cold-swaging.—C. O.

The Production of Pressed Steel Ogee Gutters. (Sheet Metal Industries, 1947, vol. 24, July, pp. 1417–1418, 1420). A solution is offered to the problem of designing pressing dies for making gutters of pressed steel sheet.—R. A. R.

The Movement of Segregates, and Deformation when Rolling Mild Steel, from Investigations at a Wire Mill. K. Krebs. (Stahl und Eisen, 1947, vol. 66–67, July 17, pp. 244–250). The causes of defects which arose in the finishing stages in the manufacture of bolts and rivets from rolled and drawn rods were studied. The defects took the form of cracks, flaking, and poor drawing properties. Unsymmetrical deformation at the ends of the rolled bars and semi-finished materials were examined by etching sections. The unusual deformation was attributed to non-uniform heating in the pusher furnace where the underside of the bars in contact with the water-cooled skids absorbed less heat than the upper portions. Subsequent rolling and drawing displaced segregates from the core to the hot side where they were elongated in some cases to a length of 10–11 cm. Alterations were made to the furnace plant which overcame the trouble.—R. A. R.

Inspection and Despatch in a Steel Wire Mill. C. Coates. (Wire Industry, 1947, vol. 14, July, pp. 381–383). The organization of the inspection and despatch departments of the wire mill of Frederick Smith and Co., Ltd., Halifax, is described.—C. O.

German Light Chain and Wire Forming Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1346: H.M. Stationery Office).

German Wedge Wire Industry. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1195: H.M. Stationery Office). A report is presented on the productive capacity of German firms in the British Zone engaged in the manufacture of wedge wire for coal screens.—R. A. R.

Electrical Methods for Diamond-Die Production. C. G. Peters, W. B. Emerson, K. F. Nefflen, F. K. Harris, and I. L. Cooter. (Journal of Research of the National Bureau of Standards, 1947, vol. 38, May, pp. 449–464). An account is given of electrical methods which have been developed for the manufacture of diamond wire-drawing dies 0·0005–0·0015 in. in dia. Very-high-quality dies may be produced much more quickly than by mechanical methods by: (1) Pilot drilling the primary cone with a high-voltage spark in air; and (2) drilling the secondary cone with a low-voltage spark in an electrolyte.—C. O.

ROLLING-MILL PRACTICE

Development of Rolling-Mills. R. Schmit. (Revue Technique Luxembourgeoise, 1947, vol. 39, Apr.–June, pp. 86–91). This is a review of recent progress.—R. F. F.

Design of a Mill for Rolling Semi-Finished Products. J. J. Curtin. (American Iron and Steel Institute: Preprint: Blast Furnace and Steel Plant, 1947, vol. 35, June, pp. 702–706). Considerations in the selection of the type of semi-finishing mill that will best fulfil the requirements of the operator are discussed, and various designs of mills are described and the operating results compared.—J. R.

Rolling Mills at the Reichwerke (Hermann Göring Works) Braunschweig. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1287: H.M. Stationery Office). The equipment and practice at the rolling mills of the Paul Pleiger Hütte Stahlwerke, Braunschweig are described in detail. The mills include a 42-in. cogging mill, a 32-in. reversing two-high roughing mill, a 20-in. continuous billet mill and an 8-in. wire rod mill.—M. A. V.

Modernisation of the Wire-Rod Mill. (Iron and Coal Trades Review, 1947, vol. 155, July 18, pp. 119–120). The installation of a 19-stand, straight-through, two-strand continuous rod mill as part of the extensive reconstruction programme at the Manchester works of Messrs. Richard Johnson and Nephew is described.—J. R.

The Joliet Coarse Rod Mill. R. R. Snow. (American Iron and Steel Institute: Blast Furnace and Steel Plant, 1947, vol. 35, June, pp. 687–690). The operation of the coarse rod mill at the Joliet works of the American Steel and Wire Co., designed for the production of $\frac{11}{32}$–$\frac{57}{64}$-in. rods from 2½-in. × 2½-in. × 30-ft. billets, is described. The mill consists of five 16-in. roughing stands, six 14-in. intermediate stands, two 12-in. finishing stands arranged in tandem, and four separate 12-in. finishing stands.—J. R.

Rolling of Sheets and Plates. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1946, Aug.–Sept., pp. 134–139). This is a review of current practice, and the statistics are given for the production of sheets and plates in various countries.—R. F. F.

Details of a New 18-in. Reversing Cold Steckel Mill. L. W. Law. (Sheet Metal Industries, 1947, vol. 24, July, pp. 1349–1351, 1365). A detailed description is given of a new reversing Steckel mill (a four-high stand driven by the strip which is pulled through it against a back tension) for making cold-reduced 3% silicon steel strip with special directional magnetic properties.—R. A. R.

Samuel Fox and Co.'s Strip and Wire Plant. (Wire Industry, 1947, vol. 14, July, p. 387). An account is given of the reorganization and development of the wire and strip mills of Samuel Fox and Co., Ltd., Sheffield.—C. O.

Interesting Features of a New Wide Strip Mill at the Firminy Steelworks. P. Blain. (Sheet Metal Industries, 1947, vol. 24, Aug., pp. 1569–1571). **New Processes for Rolling Thin Plates and Sheets.** P. Blain. (Revue de l'Industrie Minérale, Mémoires, 1944, June, pp. 257–271). An illustrated description is given of the wide strip mill which was installed in 1942 at the Aciéries et Forges de Firminy. Features of note are: (*a*) The train consists of two reversing mills, the two-high blooming and the four-high finishing, driven by the same 16,500 h.p. motor; (*b*) the housings of the finishing mill were constructed from 5-in. plates; (*c*) the roll pressure of the finishing mill is adjusted by a hydraulic device, instead of the usual screwdown; (*d*) the coilers are constructed on the principle of boiler-plate bending machines and are capable of dealing with material 1 in. thick.—C. O.

Cold-Worked Electrical Low-Loss Steels. (Electrical Times, 1947, vol. 112, Aug. 14, pp. 177–181). An account is given of the processing of hot-rolled silicon-steel strip for the production of an alloy steel with low-hysteresis-loss properties.—J. R.

Factors Affecting the Magnitude of Rolling Loads. E. C. Larke. (Journal of the Birmingham Metallurgical Society, 1947, vol. 27, Mar., pp. 226–251.) In order that a rolling mill may be used at its maximum productive capacity, and to avoid expensive mechanical breakdowns due to excessive loads, it is necessary that the designer should have reliable information regarding the maximum permissible rolling load to enable him to reduce the factor of safety, and thus avoid the installation of too heavy a unit. The factors affecting the rolling load during cold-rolling are described in detail. —R. L. B.

Progress in Steel Pipe Manufacture with Particular Reference to Seamless Pipe. E. N. Sanders. (American Iron and Steel Institute, Preprint: Blast Furnace and Steel Plant, 1947, vol. 35, June, pp. 691–694). The production of steel pipe is discussed, and a description is given of a mill at present under construction at the Lorain works of the National Tube Co., designed for the production of 18,000 tons of 2–4-in. seamless pipe per month.—J. R.

MACHINERY FOR IRON AND STEEL PLANT

Maschinenfabrik Sack, Dusseldorf, Rath. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1361: H.M. Stationery Office). A detailed description is given of a bloom shear of "Sack" design which incorporates several unique and important features. The machine has a shearing pressure of 1200 tons; it cuts blooms up to 16 × 18 in. using two 320-kW. motors at 734 r.p.m.—R. A. R.

Application and Maintenance of Hydraulic Equipment. C. E. Powell. (Iron and Steel Engineer, 1947, vol. 24, July, pp. 41–61). Typical modern types of hydraulic pumps, accumulators, and working circuits are described to illustrate the development of hydraulic machinery into precision equipment during the last two decades. —C. O.

Plugging Methods for Mill and Crane Motors. E. J. Posselt. (Iron and Steel Engineer, 1947, vol. 24, July, pp. 81–89). The factors to be considered in the design of plugging controls for electric motors in steelworks are enumerated. Early types of series and shunt relay plugging controls and a modern reversing rectifier method are described.—C. O.

Industrial Electronic Control. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1198: H.M. Stationery Office). This is a report of visits to 24 German firms to obtain information on the use of electronic controls in connection with speed, counting, sorting, temperature, weighing, colour registration, telemetering, measurement of mechanical strain, rolling-mill drives, and welding.—R. A. R.

Amplidyne Regulating Systems. B. Adkins. (Institution of Electrical Engineers, May, 1947, Preprint). The amplidyne is a cross-field-excited direct-current generator in which the field input is much smaller than that of a normal generator; it can therefore be applied as an automatic regulator for a wide variety of industrial equipments. Wiring diagrams of amplidynes are presented and the calculation of regulating systems is explained. —R. A. R.

Symposium on Testing of Bearings. (American Society for Testing Materials, 1947, Pamphlet). In this Symposium on the Testing of Bearings held at the Forty-Ninth Annual Meeting of the American Society for Testing Materials, in Buffalo, N.Y., on June 24th, 1946, five papers were presented, abstracts of which follow.

Life Testing of Plain Bearings for Automotive Engines. E. T. Johnson. (*Ibid.*, pp. 2–15). A detailed description is given of the construction and use of a machine, developed by the Chrysler Corporation from an original designed by A. F. Underwood, for the testing of the life of plain bearings for motor-car engines. Testing with this machine occupies $\frac{1}{8}$–$\frac{1}{10}$ of the time taken for high-load engine testing; the type of failure is basically similar in both cases. Photographs of typical failures are shown.—C. O.

Fatigue Testing Machines for Ball and Roller Bearings. T. Barish. (*Ibid.*, pp. 19–33). Photographs and diagrams of ten different machines for the fatigue testing of ball and roller bearings are presented. They include the Timken pure thrust, the Timken 8-in. and 24-in. combined load, the Marlin Rockwell, Fafnir, and Tinius Olsen combined-load, and the New Departure multiple-station radial-load machines.—C.O.

Metallographic Observations of Ball Bearing Fatigue Phenomena. A. B. Jones. (*Ibid.* pp. 35–48). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 312.

Fatigue Testing of Roller Bearings. H. R. Gibbons. (*Ibid.*, pp. 53–59). Machines used by the General Motors Corporation for the fatigue testing of roller bearings are illustrated, and the development of bearing rating curves is briefly explained.—C. O.

Testing of Bearings under Controlled Load. J. M. Frankland and C. B. Innes. (*Ibid.*, pp. 62–65). A machine designed for the testing of plain and anti-friction bearings under conditions simulating any encountered in a planetary gear-reduction system is described and illustrated.—C. O.

Progress in the Design of Elevated Steel Tanks. D. A. Leach. (Journal of the American Water Works Association, 1947, vol. 39, July, pp. 651–658). Examples of modern design of overhead steel water-tanks are given. —M. A. V.

WELDING AND FLAME-CUTTING

Ship Welding as Practised on the Tyne. N. M. Hunter and J. P. Wadling. (Transactions of the Institute of Welding, 1947, vol. 10, Aug., pp. 118–120). The welding techniques and sequences used in the construction of an 18,500-ton welded oil-tanker are summarized and illustrated.—C. O.

Ship Steel Weld Problems. E. C. Smith. (Metalen, 1947, vol. 1, July, pp. 197–201). The causes of fractures in welded steel ships are critically examined.—R. A. R.

Welding in Japanese Naval Construction. (British Intelligence Objectives Sub-Committees, 1947, Report No. B.I.O.S./J.A.P./P.R./1295: H.M. Stationery Office).

CLEANING AND PICKLING

Approach to Proper Method of Preparing Steel Sheets for Vitreous Enameling. D. J. Benoliel and W. J. Haring. (American Ceramic Society Bulletin, 1947, vol. 26, July 15, pp. 213–214). The nature of the surface reactions involved in the cleaning of metals is discussed. Cleaning appears to involve an exchange mechanism and it is essential that the cleaning agent for enamelling steels should effect a complete exchange with those "soils" which might cause difficulty in subsequent operations, and should not leave a residue which would interfere with pickling, nickel flashing, or enamelling.—C. O.

Manufacturing Economies Result from Barrel Finishing. H. Chase. (Materials and Methods, 1947, vol. 25, June, pp. 84–88). The "Roto-Finishing" process is described and illustrated. Burrs, tool marks, scale, etc., can be removed from small metal parts by rotation in an octagonal barrel, containing a mixture of stone chips, "Roto-Finish" compound, and water, at a speed insufficient to cause tumbling but high enough to give a scouring action. The process may also be adapted for polishing or bright-honing, and for "colouring" or increasing lustre.—C. O.

The Possibilities and Limitations of Electrolytic Polishing—A Survey of the Present Position. A. F. Brockington. (Sheet Metal Industries, 1947, vol. 24, July, pp. 1414–1416).—R. A. R.

Some New Ideas on Electrolytic Polishing. P. A. Jacquet. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct. 23–26, 1945, pp. 52–58).

Electrolytic Polishing. Method of Superfinishing. M. Mondon. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct. 23–26, 1945, pp. 59–66).

Development of Electrolytic Polishing in Great Britain. S. Wernick. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct. 23–26, 1945, pp. 67–72).

Superfinishing. J. Misset and P. Revel. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct. 23–26, 1945, pp. 153–160).

Electropolishing—What is its Status Today? C. L. Faust. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 181–194). A summary is made of American patents connected with electropolishing. The applications of the process for (1) metal finishing, (2) metal removal (*e.g.*, burrs and grinding marks), (3) preparation for electroplating, and (4) preparation for dyeing or colouring are discussed.—C. O.

Notes on Electropolishing. (Electrical Engineer and Merchandiser, 1947, vol. 24, June 16, pp. 87–88). A short outline is given of industrial electropolishing applications and techniques.—C. O.

PROTECTIVE COATINGS

Some Impressions of Electroplating in U.S.A. A. W. Hothersall. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 171–180). The author notes developments in electroplating processes and techniques which he observed during tours in America in 1939 and 1945–1946. They include: A trend towards thicker nickel and chromium plating, the use of the pyrophosphate copper bath, and "pattern" plating.—C. O.

Defects in Plating Solutions and Their Remedies. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 195–209). Practical methods for the diagnosis and cure of defects in electroplating solutions are outlined.—C. O.

The Control and Maintenance of Electro-Plating Solutions. P. Berger. (Sheet Metal Industries, 1946, vol. 23, Nov., pp. 2153–2157; 1947, vol. 24, Jan., pp. 135–140; Mar., pp. 593–597). The defects arising from the use of defective electrolytic solutions in electroplating are discussed, and recommendations are made for methods of overcoming them and preventing their recurrence. The first part deals with troubles met with in copper-plating solutions. In the second part notes are given on the care and maintenance of acid copper-, brass-, and silver-plating solutions.—C.O.

Metal Distribution from a Plating Bath. J. B. Mohler and H. J. Sedusky. (Iron Age, 1947, vol. 160, July 17, pp. 56–59, 144). Factors affecting metal distribution in electroplating baths, such as current distribution, throwing and covering power, polarization, and plating range, are simply explained, and their influence on plating quality is considered.—C. O.

Finishing Steel for Decorative and Protective Purposes. R. L. Kenyon. (American Iron and Steel Institute, May, 1947, Advance Copy). Recent developments in the surface finishing of rolled ferrous metals are summarized.—C. O.

The Surface Condition and the Properties of Electrodeposits. A. Glazunov and L. Jenicek. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct., 23–26, 1945, pp. 85–89).

Epitaxy in Electrodeposits. G. A. Homes and M. Maquestiau. (Commission Technique des Etats et Propriétés de Surface des Métaux, Conference on Surface Condition, Paris, Oct. 23–26, 1945, pp. 90–91). The effect of the crystalline structure of the base metal upon that of the metal deposited upon it is discussed.—R. A. R.

Automatic Conveyors for Electroplating. A. Bregman. (Iron Age, 1947, vol. 159, June 19, pp. 68–74; June 26, pp. 58–64). The development of automatic equipment for electroplating is reviewed and the principal features of the conveyors now in common use are described, with details of plating costs and characteristics.—C. O.

Largest Automatic Plating Plant in the World. (Metal Finishing, 1947, vol. 45, July, pp. 67–68). A short account is given of the equipment at a fully automatic electroplating plant. The plant, for the plating of motor-car parts, is divided into three sections, for copper, nickel, and chromium plating respectively—C. O.

Hard Chromium. D. Chambaud. (Mécanique, 1946, vol. 30, July, pp. 175–177). The electrodeposition of hard chromium on steel is described. The properties and uses of hard-chromium coatings are summarized. R. F. F.

Metal Surfacing by Hard Chromium Plating. E. H. Halvorsen. (Metal Treatment, 1947, vol. 45, July, pp. 71–76). An account is given of the use of hard chromium plating on machine tools. The properties of plated tools are compared with those of unplated tools, sintered carbides, and stellite.—C. O.

No Electric Current Used in New Method of Plating Nickel and Cobalt on Metal Surface. (American Electroplaters' Society: Steel, 1947, vol. 121, July 28, pp. 84–88, 100–102). In this report on the 1947 Annual Convention of the American Electroplaters' Society reference is made to a process developed by A. Brenner and G. E. Riddell for coating metals with nickel and cobalt. The coating is formed by the chemical reduction of a nickel or cobalt salt with hypophosphite in hot solution.—R. A. R.

Bright Zinc Plating Cuts Cost at Philco Plant. C. W. Smith. (Iron Age, 1947, vol. 160, July 10, pp. 46–50). Bright zinc plating is being used to replace cadmium plating on sheet-steel radio and television parts at the Philadelphia works of the Philco Corporation. The rapid and efficient plating operation is described in detail.—C. O.

Full Automatic Hot Zinc Galvanizing of Tanks. R. F. Ledford. (Iron Age, 1947, vol. 160, July 31, pp. 56–60). Types of fully automatic conveyor systems used in hot-dip galvanizing steel tanks are described.—C. O.

New Type of Electric Galvanizing Bath. B. Allert. (Australasian Engineer, 1947, June 7, pp. 75–77). The shortcomings of coke- or gas-fired galvanizing baths and of early types of electrically heated galvanizing baths are discussed. The advantages of furnaces of the "split" and "ring" types are summarized.—C. O.

The Production and Application of Heat-Resisting Aluminium Coatings. G. Kremer and K. E. Folk. (Stahl und Eisen, 1947, vol. 66–67, July 17, pp. 250–255). After describing the different processes by which iron and steel can be given heat-resisting aluminium coatings, the properties, especially the limits of heat-resistance, are discussed. Both alloy and plain carbon steel and cast steel can be protected by aluminium coatings, but cast iron requires special conditions. The heat-resistance of the coating depends on how it is produced; in this respect the powder-diffusion and the dipping diffusion processes are the best. Steel should, when possible, be welded before the coating is applied. Examples of aluminium-coated vessels and their behaviour in oxidizing atmospheres and in atmospheres containing H_2S are cited.—R. A. R.

Cold-Rolled Strip, Thermally and Electrically Tinned. (Metalen, 1947, vol. 1, Aug., pp. 225–229). [In Dutch]. A description is given of the sequence of processes in the continuous cold-rolling and electrolytic tinning at high speed of steel strip, as practised at American plants.—R. A. R.

Continuous Electrotinning of Strip Steel in the Manufacture of Tinplate. C. Frenkel. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 129–139). The principal features of the "Ferrostan" continuous electrotinning process are described and illustrated.—C. O.

Electrical Equipment for Continuous Strip Electro-Tinning Lines. P. F. Grove. (Journal of the Electrodepositors' Technical Society, 1946, vol. 21, pp. 139–142). A brief account is given of the types of electrical apparatus required for handling, tinning, and heating in the continuous electrotinning process.—C. O.

Electrodeposition of Tin in the Manufacture of Tinplate. C. Frenkel. (Swansea and District Metallurgical Society, 1947, Feb. 22, Pamphlet). After a short outline of the simple theory of electrotinning, the author describes the layout and operation of a plant using the "Ferrostan" process.—C. O.

Test Shot Blasting for Sealing Sprayed Lead Coatings. (Iron Age, 1947, vol. 160, July 31, p. 60). Tests are briefly described which showed that shot-blasting may be used to reduce the permeability of sprayed lead coatings if light undercoatings of "Metcoloy" or "Spraysteel 10" are present to maintain the bond with the base metal.—C. O.

The Application of Wear-Resistant Layers by Welding. W. F. Happé and A. W. Fondu. (Nederlandse Vereniging voor Lastechniek, Lassymposium, 1947, June, pp. 106–123). [In Dutch]. Spraying and welding methods of depositing wear-resistant alloys on steel surfaces are described, with special reference to the Powderweld, Sprayweld, and Sporkert procedures.

The Production of Ply Metals and Similar Materials in Germany. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1353: H.M. Stationery Office). An account is given of the laminated or clad metal products made by nine German firms.—C. O.

Preparing Steels for Porcelain Enameling. G. H. McIntyre. (Steel, 1947, vol. 121, July 21, pp. 102–103, 112–120). The effect of a "nickel flash" on the enamelling properties of mild steel is discussed. A review is made of literature on the subject and the commercial techniques which have been published are summarized.—C. O.

Protective Organic Coatings as Engineering Materials. J. T. Mattiello. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 493–592). A short outline is given of the chemistry of the raw materials from which organic coatings are made; the various types of coating are classified, the functions of their constituents are explained, and a detailed summary is made of their applications in the fields of corrosion, insulation, protection of food containers, colouring, and luminescence.—C. O.

Preparation of Automotive Parts for Painting by Phosphate-Spray Coating. (Industrial Heating, 1947, vol. 14, July, pp. 981–984). The bonderizing (phosphate-coating) equipment used at the automobile factory of the Udylite Corporation, Detroit, Michigan, is described briefly.—C. O.

Water Immersion Testing of Metal Protective Paints. W. W. Kittelberger and A. C. Elm. (American Chemical Society: Industrial and Engineering Chemistry, 1947, vol. 39, July, pp. 876–881). Experiments are described in which painted steel panels were immersed in sodium chloride solution and the rate and amount of absorption of water of isolated panels was compared with those of identical panels in electrical contact with freely corroding bare panels. Four linseed-oil-type coatings, with pigments of red lead, zinc yellow, chrome yellow, and iron oxide, were used. The data show that over 90% of the total water absorbed was transferred into the film under the influence of electro-endosmosis, *i.e.*, because of an electric potential gradient.—C. O.

POWDER METALLURGY

Some New Processes in Powder Metallurgy. G. Wassermann. (Metallforschung, 1947, vol. 2, May, pp. 129–137). The new processes of production, based on powder metallurgy, which are described, include: (1) Iron rings made separately by powder metallurgy successfully bonded together into a tube by stacking them after coating the contact surfaces with a mixture of iron powder in water, placing a 5-lb. weight on top, and sintering for 3 hr. at 1000° C.; (2) long bars and tubes of sintered metal powders successfully made by filling a tube with metal powder and drawing it down through dies; (3) bushes with excellent properties made by die-pressing sintered compacts while they were still hot. The properties of the bushes made by process (3) are critically examined.—R. A. R.

Powder Metallurgy. R. Girschig. (Mémoires de la Société des Ingénieurs Civils de France, 1946, vol. 99, Jan.–Apr., pp. 1–28). The author describes in detail the sintering of powders with one or several constituents and considers their possible uses and limitations. Other sections deal with the manufacture of metal powder and of sintered metal carbides, self-lubricating bearings and mechanical applications of sintered iron.—J. C. R.

United States Patents on Powder Metallurgy. R. E. Jager and R. E. Pollard. (United States Department of Commerce, National Bureau of Standards, 1947, Miscellaneous Publication M184). A classified list is made of U.S.

patents on production, handling and working, alloying, and applications of metal powders covering the period from 1836 to Jan. 1, 1947.—M. A. V.

Powder Metallurgy. G. H. S. Price. (Metal Treatment, 1947, vol. 14, Spring Issue, pp. 42–65; Summer Issue, pp. 113–130). An indexed bibliography of the literature on powder metallurgy containing 934 references is presented.—R. A. R.

Some Aspects of German Powder Metallurgy (Preliminary Assessment). (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 78: H.M. Stationery Office). The report includes a list of German processes for the production of iron powders and of German manufacturers of iron powders and sintered iron and steel products.—M. A. V.

The Evaluation of Low Carbon Steels for Deep Drawing by Means of "Blue Brittleness" Fractures. Z. Jaglarz. (Hutnik, 1946, No. 1, pp. 41–43). [In Polish]. Samples 250 × 40 × 250 mm. cut from bars or flats were notched 2 to 4 mm. deep and fractured at 350° C. The effects of the piping zone, of segregation, and of inclusions were distinctly shown. The advantages of this testing method are discussed.—W. J. W.

Polariscope. (British Engineering Export Journal, 1947, vol. 30, Aug., p. 221). Brief particulars are given of the D.B. polariscope, designed by David Brown and Sons (Huddersfield) Ltd., for the study of stress distribution in components.—R. E.

The Influence of the Degree of Cold-Work, and of Temperature and Time of Annealing on the Mechanical Properties and Structure of Cold-Rolled and Annealed Steel Strip. S. Gockowski, H. Makowski, and M. Radwan. (Hutnik, 1946, No. 1, pp. 14–25). [In Polish]. Steel strip (C 0·05%) 700 mm. wide by 3 mm. thick, was cold-rolled to 0·35 mm. in ten passes by the Sedzimir continuous process. After each pass, samples were annealed in the 600–1000° C. range for varying times of 5 to 90 min., and the mechanical properties, including the response to the Erichsen tests, were examined. It was found that tensile strength in the longitudinal direction increased continuously, but that in the transverse direction it increased with reductions up to 70%, after which it decreased. It is concluded that the most heavily cold-rolled sheet, when annealed, is the most suitable for deep-drawing.—W. J. W.

The Relation between the Analysis and Hardenability of Steel according to Recent American Investigations. S. Bækström. (Jernkontorets Annaler, 1947, vol. 131, No. 8, pp. 271–288). [In Swedish].

The Annealability of White Iron in the Manufacture of Malleable Iron. S. W. Palmer. (Institute of British Foundrymen, June, 1947, Paper No. 876). A report is presented on work carried out and in progress at the laboratories of the British Cast Iron Research Association on the annealability of white iron. The annealability of whiteheart and blackheart malleable irons is dealt with separately; the effects of sulphur and of residual alloying elements on the decomposition of the eutectic cementite have received special attention. Finally, a dilatometric apparatus for making annealability tests is described.—R. A. R.

PROPERTIES AND TESTS

The Properties of Metals and Alloys Are the Expression of Their Structure. A. Portevin. (Métaux et Corrosion, 1940, vol. 15, Nov.–Dec., pp. 79–86). The author explains how the physical, mechanical, and chemical properties of metals and alloys depend on their micro- and crystal structures, and how different properties can be obtained by varying these structures.—J. C. R.

Calculating the Tensile Strength of Metals and Its Dependency on Velocity and Temperature. A. Kochendörfer. (Metallforschung, 1947, vol. 2, June, pp. 173–186). The stress-strain curve for single crystals is used to calculate the stress-strain relationship and the tensile strength of polycrystalline cubic face-centred metals. The effects of velocity and temperature on the strength of polycrystalline metals are also derived from data on single crystals. Calculated results for aluminium and copper were found to be in good agreement with test data—R. A. R.

Proposed Experiments for Further Study of the Mechanism of Plastic Deformation. J. S. Koehler and L. Seity. (Journal of Applied Mechanics, 1947, vol. 14, Sept., pp. A-217–A-224). The "dislocation" theory of the plastic deformation of solids is outlined and discussed. It is suggested that determinations should be made of the internal friction, electrical resistance, and rate of creep of single crystals of pure metals; an experiment which would enable the dislocations in a silver chloride crystal to be "seen" is proposed.—C. O.

Influence of Plastic Extension and Compression on the Fracture Stress of Metals. D. J. McAdam, jun., G. W. Geil, and W. H. Jenkins. (American Society for Testing Materials, 1947, Preprint 30). The results of longtitudinal and transverse tensile tests on cold-extended steel plates and previously compressed steel bars are presented. It is shown that the general influence of plastic deformation on the breaking stress is a work-hardening effect, similar to the influence of the flow stress.—C. O.

Thermo-Elasticity Recorder. S. Chevenard and E. Joumier. (Académie des Sciences, 11 Nov., 1940: Métaux et Corrosion, 1940, vol. 15, Nov.–Dec., pp. 93–95). An appliance is described for recording thermo-elasticity curves.—J. C. R.

A Principal Stress Method of Stress Analysis. H. B. Maris. (Journal of the Franklin Institute, 1947, vol. 244, July, pp. 27–62). The principal stress differences, $(P–Q)$ and $(P–R)$ of the Lamé equations and their constant-value lines are identified by the new words "detend," "double-detend" and "equidetend." Principal stresses are defined as real components of stress. The Xx/x terms of the Cauchy equations with all derived terms such as shear are shown to be imaginary components of force per unit area. A gradient triangle, with sides ΔP, ΔQ, and $\Delta(P–Q)$ representing the maximum gradients of P, Q, and $(P–Q)$, is developed graphically. Five equations defining elements of the gradient triangle in terms of five measurable quantities $(P–Q)$, $(P–Q)/\Delta(P–Q)$, $ds_3/d\alpha$, ω and θ are given, where ds_3 is the normal distance between two near isoclinics, α and $\alpha + d\alpha$. The angles ω and θ are measured respectively between a stress axis line taken in the direction of increasing stress and an isoclinic and $\Delta(P–Q)$. The properties of the gradient triangle are used to solve several symmetrical stress problems and to integrate along two lines through a stress field.—R. E.

Brittle Lacquer Technique. H. Dobkin. (Steel, 1947, vol. 121, Sept. 1, pp. 70–71, 98–99). The determination of the stresses in a forged aluminium impeller by the use of brittle lacquer coatings is described and illustrated.—C. O.

Further Developments in Fatigue-Strength Calculations. E. Siebel and M. Pfender. (Stahl und Eisen, 1947, vol. 66–67, Sept. 11, pp. 318–321). The manner in which the fatigue strength of specimens is affected by the decrease in stress from the surface towards the centre, and by notches is discussed. Examples of the calculation of bending-fatigue-strength are presented.—R. A. R.

New Apparatus for Axial-Load Fatigue Testing. W. N. Findley. (A.S.T.M. Bulletin, 1947, Aug., pp. 54–56). A detailed description is given of a machine for fatigue-testing in axial tension or compression, in which provision is made for the detection and correction of strains introduced during the insertion of the specimen into the grips.—c. o.

A New Fatigue Strength-Damping Criterion for the Design of Resonant Members. J. Marin and F. B. Stulen. (Journal of Applied Mechanics, 1947, vol. 14, Sept., pp. A-209–A-212). It is shown by a theoretical analysis that the load resistance of a resonant member is a function not only of the fatigue strength but also of the damping constant and modulus of elasticity. The application of the theory to design is indicated.—c. o.

The Construction and Testing of Welded Structures in Germany with Particular Reference to Fatigue Testing. (British Intelligence Objectives Sub-Committee, 1947, Final Report No. 1486 : H.M. Stationery Office). Reports are made on the interrogation of German scientists and engineers on the subject of wartime developments in the design and testing of welded structures, such as bridges and pressure vessels. An apparatus for the fatigue testing of pressure vessels is described.—c. o.

Some Changes in Physical Properties of Steels and Wire Rope during Fatigue Failure. P. E. Cavanagh. (Canadian Mining and Metallurgical Bulletin, 1947, July, pp. 401–411). The work of several investigators on non-destructive methods of determining changes in physical properties of steels subject to fatigue stresses is reviewed. A brief account is given of a practical application—the continuous inspection of a mine-hoist cable by the measurement of changes in magnetic properties.—c. o.

Hardenability of Alloy Steels. (American Iron and Steel Institute, June, 1947 ; Contributions to the Metallurgy of Steel, No. 11). The ranges of chemical composition of the " H " steels are tabulated and 61 charts showing tentative hardenability bands are presented.—c. o.

Hardenability and Strength of Case-Hardened Machine Steel. J. E. Erb and D. M. Woolf. (Steel Processing, 1947, vol. 33, July, pp. 417–419). The results of Jominy hardenability, bend, impact, fatigue, and tensile tests on a low-carbon machining steel in the as-received and case-hardened conditions are presented. It is shown that a light cyanide case gives a hard wear-resisting surface, without loss of tensile strength, and with an almost threefold increase in fatigue limit.—c. o.

Testing Hardness up to 700° F. A. L. Pranses. (Metal Progress, 1947, vol. 52, Aug., pp. 249–250) A brief note is made of a method of measuring hardness at temperatures of up to 700° F. on the anvil of a Rockwell machine, using a small tubular electrical resistance furnace, and a powder known as " Tempilstik " for indicating the temperature.—c. o.

Uses of Shot Peening Other Than for Fatigue Durability. J. L. Wieschhaus. (Product Engineering, 1947, vol. 18, Aug., pp. 122–127). Unusual applications of shot-peening, such as for the inhibition of stress-corrosion cracking, the reduction of porosity, the testing of the adherence of silver plate, and the improvement of the lubricating properties of plain bearings, are described. —c. o.

Magnetostriction of Transformer Steel Subjected to Thermomagnetic Treatment. J. Shur and A. Khokhlov. (Academy of Sciences of the U.S.S.R. : Journal of Physics, 1946, vol. 10, No. 6, pp. 540–542). A description is given of an investigation of the effect of cooling from above the Curie point down to room temperature, in the presence of an external magnetic field, on the magnetostriction of transformer steel. It is concluded that a strongly pronounced magnetic "texture" is produced, but that it does not markedly affect the magnetization curves because of the influence of other stresses caused by the treatment.—c.o.

Measurement by Induction Heating of the Temperature Variations of the Specific Heats of Ferromagnetic Materials. G. J. Aitchison. (Journal of Scientific Instruments, 1947, vol. 24, Aug., pp. 200–202). Graphs are presented showing the variation with temperature of the specific heats of iron, cobalt, and nickel. The curves were obtained by measuring the rates of temperature rise of specimens at different temperatures in a high-frequency induction furnace designed to supply heat to the specimens at a constant rate.—c. o.

Boron in Steel. M. C. Udy. (Metal Progress, 1947, vol. 52, Aug., pp. 257–264). Recent literature on investigations of the microstructure and physical properties of boron-treated steels is summarized.—c. o.

Influence of Boron on Some Properties of Experimental and Commercial Steels. T. G. Digges and F. M. Reinhart. (Journal of Research of the National Bureau of Standards, 1947, vol. 39, July, pp. 67–131). The influence of boron additions (with simple and complex ferro-alloy " intensifiers ") on the structure and properties of experimental and commercial steels has been investigated. The effect of deoxidation on physical properties, the influence of boron on transformation temperatures and weldability, and the recovery of boron on remelting were also studied in the experimental steels.

The hardenability of many of the experimental and all of the commercial, steels was markedly increased by boron, but no correlation was found between hardenability and boron content, apparently because the magnitude of the effect depends upon the form in which boron is present in the austenite, and not necessarily on its quantity. Small amounts of boron were often beneficial in increasing notch impact properties at room temperatures for steels fully hardened and tempered at low temperatures ; but boron was either without effect or detrimental to toughness in hardened steels tempered at high temperatures.—c. o.

Life of Stranded Steel-Wire Ropes—Secondary Bending and Internal Pressure Effects. T. Wyss. (Iron and Coal Trades Review, 1947, vol. 155, Aug. 29, pp. 397–401 ; Sept. 5, pp. 441–443). The influences of secondary bending and internal pressures on the life of stranded steel ropes are treated mathematically.—c. o.

Metallurgical Examination of a Type 91, Change 3, 18-Inch Japanese Torpedo. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1446 : H.M. Stationery Office).

Metallurgical Examination of Japanese Kasei-21 Aircraft Engine No. 2189. (British Intelligence Objectives Sub-Committee, 1947, Report No. B.I.O.S./J.A.P./P.R./1507 : H.M. Stationery Office).

CORROSION

The Mechanism of Corrosion Fatigue of Steel in Acid Solution. M. T. Simnad and U. R. Evans. (Journal of the Iron and Steel Institute, 1947, vol. 156, Aug., pp. 531–539). Corrosion fatigue in hydrochloric acid shows certain analogies to, but also marked differences from, that in potassium chloride. At the end of an incubation period, rounded pits develop into cracks, the residual strength sharply declines, the rate of chemical corrosion (hitherto constant) greatly increases, and the potential drops ; these four changes occur sooner at

high than at low stress ranges. A cathodic current can prevent detectable chemical attack, but does not greatly increase life. The results are best explained by the changes produced by stress within the metal, in contrast to a rupture of films, which may be important in neutral solutions.—R. A. R.

Stress Corrosion Cracking of Welded Mild Steel Gas Mains. (Gas Times, 1947, vol. 52, Aug. 2, p. 161). The tentative interim conclusions reached by a committee of the British Welding Research Association studying the cracking of welded mild-steel gas mains are summarized. —C. O.

Corrosion and Embrittlement of Boiler Metal at 1350 Pounds Operating Pressure. L. E. Hankison and M. D. Baker. (Transactions of the American Society of Mechanical Engineers, 1947, vol. 69, July, pp. 479–486). An investigation of the cause of barnacle corrosion and embrittlement which occurred in three boilers at the Springdale Station of the West Penn Power Company after seven years of service is reported. It is considered that an iron sulphite-phosphate compound from the feedwater which had protected the surfaces was removed during an acid cleaning, thus allowing corrosive barnacles to form.—C. O.

Experiences with Internal-Boiler-Surface Corrosion in 1450-lb. Open-Pass Boilers at West End Station of The Cincinnati Gas and Electric Company. E. H. Mitsch and B. J. Yeager. (Transactions of the A.S.M.E., 1947, vol. 69, July, pp. 487–491). The conditions of operation of three continuously slagging open-pass boilers operating at 1450 lb./sq. in., are compared in order to determine the causes of various types of corrosion which occured in them during nine years of operation. —C. O.

Wall Tube Corrosion in Steam-Generating Equipment Operating Around 1300 Psi. F. G. Straub. (Transactions of the A.S.M.E., 1947, vol. 69, July, pp. 493–499). The author describes several instances of boiler-tube failures of the brittle and non-brittle types. In the brittle type, intercrystalline cracks occur in decarburized areas under the corrosion products on the water side of the tube, perhaps because of the presence of dissolved oxygen in the feedwater and the absence of an " oxygen scavenger " in the boiler water. Non-brittle corrosion is attributed to caustic attack of the metal, without intercrystalline cracking.—C. O.

Corrosion-Resistant Sheet Steel in Marine Atmospheres. W. Mutchler. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 621–639). Thin cold-rolled 18/8 chromium–nickel steels have been exposed for periods up to three years in marine atmospheres, and continuously and intermittently in sea-water, at Hampton Roads, Virginia, Kure Beach, North Carolina, and Chapman Field, Florida. Visual examination and bending fatigue tests showed that the most rapid corrosion occurred during the first six months of exposure, and that thereafter the rate of attack was much slower. The effects of most of the different stabilizing elements added to the 18/8 steels were very similar, except that steels containing molybdenum were less susceptible to rust formation.—C. O.

Atmospheric Corrosion Tests on Corrosion-Resistant Steel. G. L. Snair. (Proceedings of the American Society for Testing Materials, 1946, vol. 46, pp. 643–651). The results of ten-year exposure tests of chromium and chromium–nickel steels, after various heat-treatments and with various surface finishes, in an industrial atmosphere at Brackenbridge, Pennsylvania, are summarized. Among the general conclusions are : (1) The corrosion resistance of straight 12–28% chromium steels increases with increasing chromium content ; (2) any increase in the chromium content above 18%, or in the nickel content above 8% does not appreciably improve the corrosion resistance of chromium–nickel steels ; (3) the modification of chromium–nickel steels, with columbium, titanium, or vanadium does not improve the corrosion resistance in the fully annealed condition, but does considerably improve the resistance of metal heat-treated at 1200° F. ; (4) welding of the stainless alloys causes little or no decrease in corrosion resistance.—C. O.

Zinc–Iron Couple in Water at Elevated Temperatures. G. D. Lain. (American Hot-Dip Galvanizers' Association: Corrosion and Material Protection, 1947, vol. 4, July-Aug., pp. 12–15). The literature on the corrosion of zinc-coated iron at temperatures above 140° F. is discussed, with special reference to the possibility of a reversal in potential of the zinc–iron couple.—C. O.

Automobile Exhaust Valve Materials and Lead Attack. R. J. Brown. (Metallurgia, 1947, vol. 36, July, pp. 149–154). Two forms of corrosion resulting from lead attack on automobile exhaust valves are considered and the opinion is expressed that the ideal alloy for these valves has yet to be discovered. As the problem is thought to be one of faulty combustion rather than of faulty metallurgical technique it concerns the fuel technologist, but close co-operation with the designer and the metallurgist is vital if the demands for increased engine efficiency are to be met.—J. R.

Corrosion of Metals—Metals in Aircraft Engine Cooling Systems. P. F. Thompson. (Australian Council for Aeronautics, 1946, May, Report ACA-24). A general account is given of the theory of corrosion of the hydrogen-ion-discharge, oxygen-ionization, and cupric-ion-discharge types, and the theory is applied to problems arising in the cooling systems of aircraft engines in which glycol and glycol solutions are used. The application of electrochemical methods in determining the controlling factors in corrosion problems is discussed. The growth and breakdown of films on metals has been traced under varying conditions of temperature and aeration. The mechanism of the formation of films on aluminium is studied in detail.—C. O.

Scaling at High Temperatures in Sulfur Dioxide, Oxygen and Nitrogen-Containing Atmospheres. J. H. Nicholson and E. J. Kwasney. (Electrochemical Society, 1947, Preprint No. 91-28). Data are presented on the corrosion of carbon steel, alloy steels, calorized steel, and cast iron in sulphur-dioxide/oxygen/nitrogen atmospheres at elevated temperatures. It was found that increases in temperature have a more serious effect on the rate of corrosion than increases in the concentration of sulphur dioxide or oxygen. Calorized steel and "AISI Type 316 Cb " alloy appeared to be promising materials for equipment used in sulphur dioxide atmospheres at high temperatures.—D. R. S.

Polarographic Oxidation of +4 Vanadium. J. J. Lingane and L. Meites, jun. (Journal of the American Chemical Society, 1947, vol. 69, Aug., pp. 1882–1886). A report is made on a study of the effect of adding different anions to a *1 N* solution of sodium hydroxide on the oxidation of quadravalent vanadium at the dropping electrode. The anodic waves for the oxidation of quadravalent vanadium in solutions of varying *p*H were also determined.—C. O.

Arsenic as a Corrosion Inhibitor in Sulphuric Acid. A. Wachter, R. S. Treseder, and M. K. Weber. (Corrosion, 1947, Aug., vol. 3, pp. 406–414). An account is given of investigations of the inhibiting action of arsenic trioxide and sodium meta-arsenite on the corrosion of carbon steel by strong sulphuric acid solutions at the

temperatures of hot-acid petroleum-polymerization processes. The arsenic is shown to be capable of substantially preventing corrosion at concentrations of acid of 50–72%, and temperatures up to 85° C.—C. O.

A Survey of High-Temperature Gas-Atmosphere Corrosion of Iron-Nickel-Chromium Alloys. J. T. Gow. (Corrosion, 1947, vol. 3, July, pp. 311–324; Aug., pp. 383–402). A summary is made of the quantitative data vailable in the literature on the resistance to corrosion by hot air and flue gases of the heat-resistant alloys of the system iron-nickel-chromium.—C. O.

The Protection of Ships' Bottoms and the Formulation of Anti-Corrosive Compositions. F. Fancutt and J. C. Hudson. (Journal of the Oil and Colour Chemists' Association, 1947, vol. 30, May, pp. 135–158, Reprint). A general outline is given of the work of the Marine Corrosion Sub-Committee of the Iron and Steel Institute and British Iron and Steel Research Association on the development of improved anti-corrosive compositions for ship-plates.—C. O.

Corrosion Testing Facilities Expanded at Kure Beach. R. K. Lotz. (Steel, 1947, vol. 121, July 14, pp. 88–92, 130–131). **Expanding Corrosion Testing Facilities at Kure Beach.** (Corrosion and Material Protection, 1947, vol. 4, Aug., pp. 7–9). An account is given of the facilities at the sea-water and marine-atmosphere corrosion-testing station at Kure Beach, North Carolina. Mention is made of various investigations recently completed or now in progress.—C. O.

HISTORICAL

Notes on the Historical Development of Physical Metallurgy. A. F. Dunbar. (Australian Institute of Metals, Australasian Engineer, 1947, May 7, pp. 78–86). The development of the modern science of physical metallurgy from the seventeenth century onwards is traced, with numerous references to the literature.—C. O.

Notes on the Development of the Blast-Furnace. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1945, Nov., pp. 133–136; Dec., pp. 149–152; 1946, Jan., pp. 2–5). This is a review of the development of blast-furnace practice from the middle of the last century to the present time.—R. F. F.

The French Steel Industry During the Last Hundred Years. G. Grenier. (Revue de l'Industrie Minérale, Comptes Rendus, 1946, Feb., pp. 17–20; Mar., pp. 33–36; Apr., pp. 41–44; May, pp. 61–63; June pp. 94–95). The history of the French steel industry is outlined with special reference to technical and economical progress and to producers' associations.—R. F. F.

A Factory Doctor's Duties at an Ironworks in 1724. H. R. Schubert. (Journal of the Iron and Steel Institute, vol. 156, May, pp. 27–28). Ambrose Crowley erected ironworks at Swalwell and Winlaton, near Newcastle-on-Tyne in 1690. Both he and his son took an active interest in the welfare of their workmen and a factory doctor was appointed in 1724; notes on the doctor's duties are presented in this short paper.—R. A. R.

A Cast-Iron Ring 2500 Years Old. H. R. Schubert. (Journal of the Iron and Steel Institute, 1947, vol. 156, Aug., p. 476). Some details are given of the discovery by K. Absolen of the remnants of a prehistoric smithy worked in the sixth century B.C. Sickles, keys, hoes, nails, knives, bars, and a cast-iron ring were among the articles found in a cave near Brno, Czechoslovakia. —R. A. R.

Anglo-Saxon Cutlery. H. R. Schubert. (Journal of the Iron and Steel Institute, 1947, vol. 157, Sept., pp. 22–26). The manufacture of cutlery by the Anglo-Saxons attained a very high standard in Northumbria and knives were sent abroad as special gifts, as is mentioned in letters written between A.D. 732 and 764. In these letters the knives are described as being manufactured in a special fashion customary to the country. Compared with two large knives of the "Hurbuck" type (Hurbuck was a farm in Country Durham) and a third, found at Sittingbourne in Kent, but evidently of Northumbrian manufacture, the knives mentioned in the letters had straight backs, but sloped slightly towards the point, and they were ornamented by inlay with copper, brass, or white metal. The designs used for ornamentation were probably vine-scrolls, motifs which are characteristic of Northumbrian art.

The Fordell Railway. J. C. Inglis and F. Inglis. (December, 1946; pamphlet). A well-illustrated historical account is given of the Fordell railway which connected the coal-pits of Coaltown with the port of St. David's on the Firth of Forth. This wagon-way had an unbroken existence of about 180 years until in 1946 it was relaid with steel rails and operated by locomotives.—R. A. R.

ECONOMICS AND STATISTICS

The Iron and Steel Development Plan. R. M. Shone. (Royal Statistical Society: Iron and Coal Trades Review, 1947, vol. 154, May 23, pp. 921–927; Metallurgia, 1947, vol. 36, June, pp. 77–81; Iron and Steel, 1947, vol. 20, June, pp. 321–324; July, pp. 358–361, 364; Aug., pp. 416–418). The statistical basis of the iron and steel development plan drawn up by the British Iron and Steel Federation and which was the subject of a recent White Paper is discussed. The future demand for steel, the supplies of raw materials, and the progress of the plan are considered. The article deals mainly with the first two sections of the White Paper.—J. R.

The British Iron and Steel Industry. (Metallurgia, 1947, vol. 36, July, pp. 133–136, 160). In an outline of research and development in the British iron and steel industry, mention is made of the work carried out in the industrial laboratories and in the academic institutions, as well as of the co-operative research organized by the Iron and Steel Institute and the various research associations. Details are also given of the reconstruction work in progress at various plants throughout the country, in accordance with the plan for the modernization of the industry.—J. R.

The Present-Day Position of the Steel Industry in Great Britain. A. G. Lefebvre. (Revue Technique Luxembourgeoise, 1946, vol. 38, July–Sept., pp. 2–16, Oct.–Dec., pp. 1–16). This is a general review of all aspects of the British steel industry during the war years, and the steps taken by the industry to deal with the post-war problems.—R. F. F.

The Iron and Steel Industry of India. (British Iron and Steel Federation, Monthly Statistical Bulletin, 1947, vol. 22, July, pp. 1–37). The development and present position of the Indian iron and steel industry are reviewed, and it is considered that even if the expansion recommended by the Iron and Steel Panel in 1944 is put into effect it will be some years before internal demands can be satisfied.—M. A. V.

The Future of the Steel Industry. W. Sykes. (American Iron and Steel Institute, Preprint: Blast Furnace and and Steel Plant, 1947, vol. 35, June, pp. 695–701). A statistical survey is made of American steel production and consumption, and the future prospects of the industry are discussed.—J. R.

Modernisation of the French Steel Industry. (Génie Civil, 1947, vol. 124, Apr. 15, pp. 157–158). Statistics are given showing the present position of the French steel industry, and details of the plan to increase production are described.—R. F. F.

Norway's Iron and Steel Project. (*The Times* Review of Industry, 1947, Sept, p. 68). As part of a plan to make Norway independent of imported iron and steel, a new works is to be constructed at Mo in Rana, by a company of which the State will be the chief shareholder. The Rana ores, dephosphorized by a new process providing a valuable by-product, will be employed, though Fosdalen refined ores, of 60% iron content, and Sydvaranger ore may also be used. Electric power will be obtained from the Rössågo hydro-electric plant, where the machinery will be of Italian manufacture. It is possible that the rolling-mill equipment will be purchased in England.

Three Tysland-Hole electric pig-iron furnaces are being installed and the eventual capacity of the plant is 400,000 tons of rolled products per year; it is contemplated that by 1950 Norwegian consumption will reach this figure, of which 65,000 tons will be required in shipbuilding. Plates may also be exported to foreign builders of Norwegian ships.—J. P. S.

Creating a National Argentine Steel Industry. (Mining Journal, 1947, vol. 229, Aug. 30, pp. 543–544). The "Sociedad Mixta Siderurgica Argentine," 80% of whose capital will be owned by the State and 20% by the existing metallurgical industry, has been created, as the first of several companies, to develop a heavy iron and steel industry in Argentina. Only 10% of Argentine iron ore will be used, the remaining iron intake being imported Chilean and Brazilian ore and pig iron. United States, Chilean, and British coal and coke and, on completion of the Salto Grande plant, Uruguayan hydro-electric power, will provide fuel. An initial production of 300,000 tons/annum of high-grade rolled iron and steel is contemplated, to be raised eventually to 1,000,000 tons or higher. The company will build its own port and operate its own ships.—J. P. S.

The Relation between Heat and Energy Economy and Production Conditions in the Large Iron and Steel Works. F. Wesemann. (Iron and Steel Institute, 1947, Translation Series, No. 319). This is an English translation of a paper which appeared in Stahl und Eisen, 1947, vol. 66–67, Jan. 30, pp. 35–42. (*See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 157).

MISCELLANEOUS

Some Observations on Laboratory Planning. G. B. Contractor. (Journal of the Council of Scientific and Industrial Research, India: Metallurgia, 1947, vol. 36, June, pp. 70-75). Each of the following aspects is discussed with reference to the planning of new laboratories: Shape of building, lighting; ventilation; floors and walls; chemical fume hoods; distribution of services, *i.e.*, gas, electricity, etc.; and height and arrangement of work benches.—C. O.

Trends in Metallurgical Research. C. S. Smith. (American Iron and Steel Institute, May, 1947, Advance Copy). The relationship between the physicist and the metallurgist in the future development of metals is discussed, and an outline is given of the aims of the Institute for the Study of Metals recently formed at the University of Chicago.—C. O.

BOOK NOTICES

BRIGGS, C. W. "*The Metallurgy of Steel Castings.*" 8vo., pp. x + 633. Illustrated. New York, 1946: McGraw-Hill Book Co., Inc.; London: McGraw-Hill Publishing Co., Ltd. (Price 32*s.* 6*d.*).

The author is the Technical and Research Director of the Steel Founders' Society of America and hence is well placed to prepare a book of this character, being, as it is, a complete metallurgical text-book and guide to those who are concerned with the specialized technical control which is now called for in the steel-foundry industry. The volume is a complete guide in that it deals with both the elementary and advanced metallurgical principles: it thus serves the purpose both as an instructor to the technically minded steel-foundryman and as a book of reference to those who are concerned with technical advance in the steel foundry. It was prepared to satisfy the need for a single source reference to the subject, and there is no doubt that it has amply fulfilled its purpose, and by reason of the full references which it gives to other works and publications it will be regularly used as an introduction to any intensive study in the field of steel-castings metallurgy.

The structure of the book follows the natural course of operations in the steel foundry. Steel-melting for foundries by the various processes is first considered, followed by chapters on deoxidation, tapping and pouring, and another on the physical changes taking place during the cooling and solidification of liquid steel, with especial reference to the control of contraction and to the control of directional solidification. Acid and basic steel-melting processes are considered in separate chapters, and, whilst this may be preferable to the practical foundryman who is concerned with one or other practice, it leads to some duplicate reading for those whose interests are wider or are limited to more specialized foundry technology. There are chapters dealing with gates and risers, moulding sands and cores, and the various types of defects which can occur in steel castings unless proper foundry control is exercised to avoid them. Further chapters then deal with the various fettling operations (including hydroblasting), with heat-treatment and metallography, with the welding of steel castings both for composite assemblies and for repairs, and the final chapter deals with the inspection and mechanical properties of the finished casting. As would be expected, due attention is given to non-destructive testing, including X-ray and gamma-ray radiography. W. C. NEWELL.

BRITTON, K. G. "*Electronic Developments.*" 8vo, pp. viii + 208. Illustrated. London: George Newnes, Ltd. (Price 7*s.* 6*d.*).

The history and principles of electronics and electronic devices are dealt with. The first chapter, devoted to the electron, deals with the discovery of ions, electron charge, mass and effective radius. Subsequent chapters describe the thermionic valve, the cathode ray tube, the Klystron, the positive grid oscillator, and the magnetron, the cyclotron, X-rays, photo-electric cells, the electron multiplier, the application of electron technique to television, the electron microscope, the mass spectrograph, and electricity in gases.—R. E.

MILLER, J. L. "*Modern Assembly Processes. Their Development and Control.*" Second Edition. Revised. 8vo, pp. xi + 199. Illustrated. London, 1946: Chapman and Hall, Ltd. (Price 18*s.*).

This book made its first appearance in 1941, and has now been revised and brought up-to-date. It deals with the following: Riveting; screws and bolts and nuts; soft soldering; hard soldering and brazing;

hydrogen furnace brazing; pressure and shrinkage fits; welding processes; electric arc welding; electric resistance welding; projection welding; resistance welding methods and fixtures; butt and flash welding and welding non-ferrous metals; welding control systems; testing, inspection and trouble hunting; and the choice of the assembly process.—R. E.

NEWTON, J. "*An Introduction to Metallurgy.*" Second Edition. 8vo, pp. vii + 645. Illustrated. New York, 1947: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 30*s.*).

This is the second edition of an elementary treatise on metallurgy, in which principles rather than practices are stressed. The book is divided into two parts, "Adaptive Metallurgy," and "Extractive Metallurgy." The term "adaptive metallurgy" has been adopted in preference to "physical metallurgy" to cover the nature and physical properties of metals and alloys, their fabrication and heat-treatment, and corrosion. In the present edition extra space has been devoted to the discussion of pyrometallurgy, new material on corrosion has been added and more alloy systems included. A section on powder metallurgy has also been added.—R. E.

SIMON, L. E. "*German Research in World War II.*" 8vo, pp. xi + 218. Illustrated. New York, 1947: John Wiley and Sons, Inc.; London: Chapman and Hall, Ltd. (Price 24*s.*).

The author was one of a group of scientists sent to Europe to examine German scientific establishments immediately following their capture by the Allies, and this book records the results of his observations of German weapons research. He reveals the lack of co-operation between civilian research foundations, industrial laboratories, and military research groups which prevented the efficient development and application of scientific knowledge.—R. E.

SNOEK, J. L. "*New Developments in Ferromagnetic Materials.*" (Monographs on the Progress of Research in Holland). 8vo, pp. 136. New York and Amsterdam, 1947: Elsevier Publishing Co., Inc. (Price 13*s.* 6*d.*).

This is one of a series of monographs specially written by research workers to report the work of scientists in the Netherlands during the five years of German occupation. The present volume is devoted to an account of the ferromagnetic materials developed in the laboratories of Philip's Gloeilampenfabrieken and includes introductory chapters on the statics and dynamics of ferro-magnetism, in addition to the following appendices: I—The Inclusion Model of Ferromagnetic Hysteresis; II—The Influence of Eddy Currents on the Apparent Hysteresis Loop of Ferromagnetic Bars, by J. L. Snoek; III—On the Decarburization of Steel and Related Questions, by J. L. Snoek; IV—On the Theory of the Elastic After Effects in Iron, by D. Polder.—R. E.

NEW PUBLICATIONS

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS. "*Electric Furnace Steel Conference.*" Sponsored by the Electric Furnace Steel Committee of the Iron and Steel Division. "*Proceedings,*" Volume 4, Pittsburgh, December 5–7, 1946. 8vo, pp. 268. Illustrated. New York: The Institute.

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